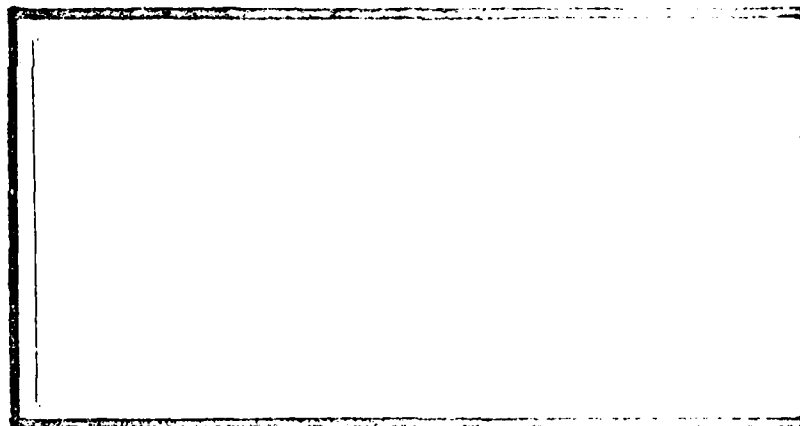


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HOW CAN AIR FORCE
CIVIL ENGINEERS USE EXPERT SYSTEMS ?

THESIS

Christopher M Hazen
Captain, USAF

AFIT/GEM/LSM/88S-9



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AFIT/GEM/LSM/88S-9

HOW CAN AIR FORCE CIVIL ENGINEERS USE EXPERT SYSTEMS?

THESIS

**Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology**

Air University

**In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Engineering Management**

Christopher M Hazen, B.S.C.E.

Captain, USAF

August 1988

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Abstract

Expert systems have great promise for increasing productivity and effectiveness. As budget cuts continue into the future, Air Force Civil Engineering will be increasingly concerned with its productivity and effectiveness. This thesis searched for Air Force Civil Engineering expert system applications using a preliminary selection criteria to discern the knowledge areas having expert system potential. Interviews were conducted with experienced civil engineers to gather the ideas.

The primary objective of this thesis was to develop a preliminary selection criteria. Donald Waterman's selection criteria was used as the basis. The questions within the selection criteria were reordered with the most discriminating questions first, to eliminate unfruitful ideas quickly. Other discriminating questions were added to the selection criteria as necessary for clarification and amplification.

Eight experienced civil engineers were interviewed during two rounds of questioning. The first round of interviews solicited and screened ideas, using the preliminary selection criteria. The first round generated twenty-one ideas, which were combined into fifteen proposals. In the second round, interviewees selected proposals having the greatest potential benefit to Air Force Civil Engineering in order. Five proposals emerged from the second round of interviewing: Job Order/Work Order Management, Design Schedule Management, Beddown of New Aircraft Systems, Facility Constraints on New Aircraft Designs, and Force Development/Force Structure.

HOW CAN AIR FORCE CIVIL ENGINEERS USE EXPERT SYSTEMS?

I. Introduction

Machines that lack knowledge seem doomed to perform intellectually trivial tasks. Those that embody knowledge and apply it skillfully seem capable of equaling or surpassing the best performance of human experts.
[Hayes-Roth and others, 1983: 3].

Air Force Civil Engineering (CE) is constantly faced with doing more work with fewer resources. As the national debt increases, and government spending becomes tighter, CE can expect little or no funding relief in the near future. To just stay "even," CE will have to improve the way they manage and do business. Key words for the next decade will be "effectiveness" and "productivity."

One avenue to productivity is through computers. CE's interest in computers has been carried to the point that CE has designed its own information system, completely separate from Air Force data processing. But to keep pace with this trend, civil engineers will need to learn new technologies and how to implement them.

Artificial intelligence offers one possible hope of increasing productivity and improving effectiveness. Expert systems, a subset of artificial intelligence, are computer based systems that capture knowledge and expertise within a program. These programs differ from conventional programming in that they represent the knowledge using heuristics versus algorithms. Few commercial expert systems are currently available, but many are projected for the near future. A great variety of expert system building tools or shells are also becoming available. These sophisticated shells or tools allow a comparative computer novice to develop a knowledge area into an expert system prototype for demonstration, testing, and possible use.

One use of expert systems would be to "capture" the expertise in short supply and distribute it to where it is needed. Civil engineering has experts in many different areas. Those experts know how to approach the problems and can explain their solutions. Experts, using expert systems, could identify guidelines for analyzing certain problems leading to their solutions.

This thesis examines the types of CE applications that might be developed into expert systems. The thesis reviews the development process of expert systems and methodologies for selecting suitable knowledge areas for development. It outlines a methodology for a preliminary evaluation of a knowledge area for expert system development.

To gather information about possible knowledge areas, experienced civil engineers will be interviewed and solicited for suggested applications. The suggested applications will be compared to a selection criteria developed for expert systems, and a listing of possible applications will be

made. Finally, the interviewees will be asked to rank the listing of possible applications in order of need, recommending areas for expert system application.

This thesis will be divided into five chapters. This first chapter briefly acquaints the reader the thesis intent. The literature review will *cover the background information* leading up to the statement of the problem. The methodology will detail how the research will proceed. The results and findings will present the information gathered and list areas that should be considered for development. Lastly, Chapter 5 will summarize the research effort, discuss the conclusions, and offer *recommendations* on future research. Definitions for the terms used in this thesis are available in Appendix A.

II. Literature Review

Overview

The purpose of this chapter is to review the literature concerning expert systems, their development, and how knowledge areas should be selected for expert systems development. The chapter covers computer development trends in civil engineering, a background on expert systems, the expert system development process, and several problem selection methodologies for expert system development.

Trends

Air Force Civil Engineers must find new ways to increase their productivity due to the anticipated yearly budget cuts from the Gramm-Rudman deficit reduction plan. Major General Clifton D. Wright, former Director of Engineering and Services HQ USAF, identified increasing CE productivity as one of the six strategic goals during his tenure (Astin and Ruff, 1984: 5). Major General George E. Ellis continued the emphasis on productivity by focusing on decentralization and greater computer usage (Sullivan, 1986: 7-8).

As the concern for productivity increased, so has the interest in computers. CE has used two major computer systems in the recent past. Initially, CE's used the BEAMS (Base Engineer Automated Management System) to provide database management. CE eventually outgrew BEAMS and made the transition to the WIMS (Work Information Management System).

BEAMS. The BEAMS was originally implemented back in 1968, giving CE a management information system (MIS). The system was developed and run by Air Force data processing. BEAMS was a good MIS for its time but it provided only standardized reports, and retrieval of specialized information was difficult. Although BEAMS had some real time capability, generally managers did not have access to it. Information was batch loaded into the computer and reports were generated overnight for use by CE (Mastrangeli, 1984: 10-11).

As BEAMS matured, users became frustrated by the system's inflexibility and lack of convenience, and hence did not make good use of the system. General Ellis summarized the situation best:

I [General Ellis] didn't like [BEAMS] primarily because it forced us to manage in the past. The only thing BEAMS let us do was to look back and see what it was we hadn't done. I coined the phrase "too late management." We needed to manage forward. I felt we could do a much better job if we managed what we had to do, not what hadn't been done [Sullivan, 1983: 5].

General Ellis' response to BEAMS was to create and support the WIMS.

WIMS. WIMS development started with several "Tiger Teams," groups of civil engineers working outside the traditional Air Force data processing function (Holt, 1987). This attempt to get into the business the data processing business was met with great resistance by Air Force data processing initially and they demanded an opportunity to try to meet CE's needs. When Air Force data processing received the first 100 typical reports the Tiger Teams wanted, they responded that it would take 21.5

man-years to accomplish the work. The Tiger Teams continued with their efforts, acquired a system, and put 300 reports on their system within 60 days (Sullivan, 1983: 7).

The end result of the team's efforts evolved into the WIMS, a user developed decision support system. The WIMS system software comes with standard reports, but also has great flexibility to generate new reports. It interfaces with BEAMS files, so previously recorded data is available. WIMS also provides a real time capability with terminal access for CE (Mastrangeli, 1984: 12-14).

Rivard and Huff have noted that more and more user's are developing their own applications:

To users, most of the advantages of [user developed applications] are related to the ultimate involvement of the user in the development process. Since users do not have to translate and communicate their information needs to outsiders, the problems inherent in determining information requirements are reduced or eliminated [Rivard and Huff, 1984: 40].

User involvement was the key part in the development of WIMS. The users understood their requirements best and were able to search and find their own solutions (Holt, 1987).

The trend toward user developed systems also seems to be evolving in the realm of expert systems.

It is of the utmost importance for any civil engineer who wishes to build an expert system to realize that one can learn to be knowledge

engineer rather rapidly, in fact many civil engineers are already knowledge engineers without even knowing it. [Ludvigsen and others, 1986: 28].

One of the contributing factors toward users developing expert systems seems to be the ease of using expert system languages.

Experienced users of microcomputer spreadsheets and databases have been able to make the transition to these expert system languages easily. The author has taught two day short courses in which persons with almost no prior computer background have been able to build simple prototype expert systems using [an expert system tool] with only limited assistance . . . [Levitt, 1986: 63]

Expert Systems

Defined. Donald Waterman in his book, A Guide to Expert Systems describes an expert system as "a computer program using expert knowledge to attain high levels of performance in a narrow problem area" (Waterman, 1986: 11). Expert systems vary from conventional programs in a number of ways (see Table 1). Conventional programs generally solve problems using algorithmic techniques to manipulate data. Expert systems differ by manipulating a knowledge base using heuristic methods dealing with ambiguous and incomplete information. Expert systems typically solve problems in the following categories: interpretation, prediction, diagnosis, debugging, design, planning, monitoring, repair, instruction, and control (Hayes-Roth, 1983: 5).

Table 1

Conventional Programs and Expert Systems Characteristics	
Conventional Programs	Expert Systems
Representation and use of data	Representation and use of knowledge
Knowledge and control integrated	Knowledge and control separated
Algorithmic (repetitive) process	Heuristic (inferential) process
Effective manipulation of large data bases	Effective manipulation of large knowledge bases
Programmer must ensure uniqueness completeness	Knowledge engineer inevitably and relaxes uniqueness and completeness constraint
Midrun explanation impossible	Midrun explanation desirable and achievable
<u>Oriented toward numerical processing</u>	<u>Oriented toward symbolic processing</u> (Maher, 1987: 4)

Nature of Expertise. To better grasp expert systems, the expertise underlying the system needs to be understood more fully. Paul E. Johnson defines an expert.

An expert is a person who because of training and experience is able to do things the rest of us cannot; experts are not only proficient but also smooth and efficient in the actions they take. Experts know a great many things and have tricks and caveats for applying what they know to problems and tasks; they are also good at plowing through irrelevant information in order to get to the basic issues, and they are good at recognizing problems they face as instances of types with which they are familiar. Underlying the behavior

of experts is the body of operative knowledge we have termed expertise [Johnson, 1983: 78].

Experts are also said to have the following attributes:

1. Experts have the ability to solve problems.
2. Experts can explain their solutions.
3. Experts learn by experience.
4. Experts can restructure their knowledge
5. Experts know when to break the rules.
6. Experts can determine the relevance of information.
7. Experts exhibit graceful degradation of performance.

Of the seven attributes experts demonstrate, expert systems can only partially demonstrate the first three (Shurkin, 1983: 75).

Roles. Expert systems can function in four roles in an organization: a "consultancy role," a "checklist role," a "refining expertise role," and a "training role" (Basden, 1984: 63-64).

Consultant. Using an expert system as a consultant, the non-specialist can obtain counsel, guidance, or information from expert systems similar to the specialist. Such a system not only frees the specialist, but increases the non-specialist's access to the needed expertise (Basden, 1984: 63-64, Allen, 1986: 9).

Checklist. In the checklist role, the expert system would question the user about a subject and lead the user to the same conclusion as the expert would derive. Experts systems can intelligently order the questions, avoid irrelevant questions, and rapidly arrive at the solution. The system might also provide documentation of the consultation for future reference (Basden, 1984: 66).

Refining Expertise. Most experts will admit to gaps in certain parts their knowledge. In creating an expert system, the knowledge must

be defined and mapped, which in turn identifies the gaps in knowledge. Experts systems can "be of significant benefit as a guide to research, by highlighting the weaknesses in current understanding" (Basden, 1984: 67).

Training. The training role is often seen as an area of great potential. Key personnel using an expert system can learn processes and decisions which represent expert knowledge.

As a training device the expert system provides new staff members with a vast reservoir of experiences and strategies from which to learn about recommended policies and methods. The system can also be adapted to train novices in specific tasks, such as claims adjusting or financial planning [Waterman, 1986: 7-8].

Components. Expert systems are generally composed of four components: the knowledge base, the inference engine, the user interface, and the development engine. Figure 1 shows the interrelation between the components. The knowledge base is a database of static data plus relational information. The inference engine actually manipulates the knowledge base using analyses, forming hypotheses, and auditing the processes per some strategy. The user interface refers to the terminal connecting the user to the system. The development engine allows the knowledge engineer to create, modify, add, or delete information from the knowledge base (Wolfgram and others, 1987: 13-15).

In addition to these components, expert systems may also have an explanation facility. This facility can be as simple as tracing the path of execution through the knowledge base or as complex as explaining

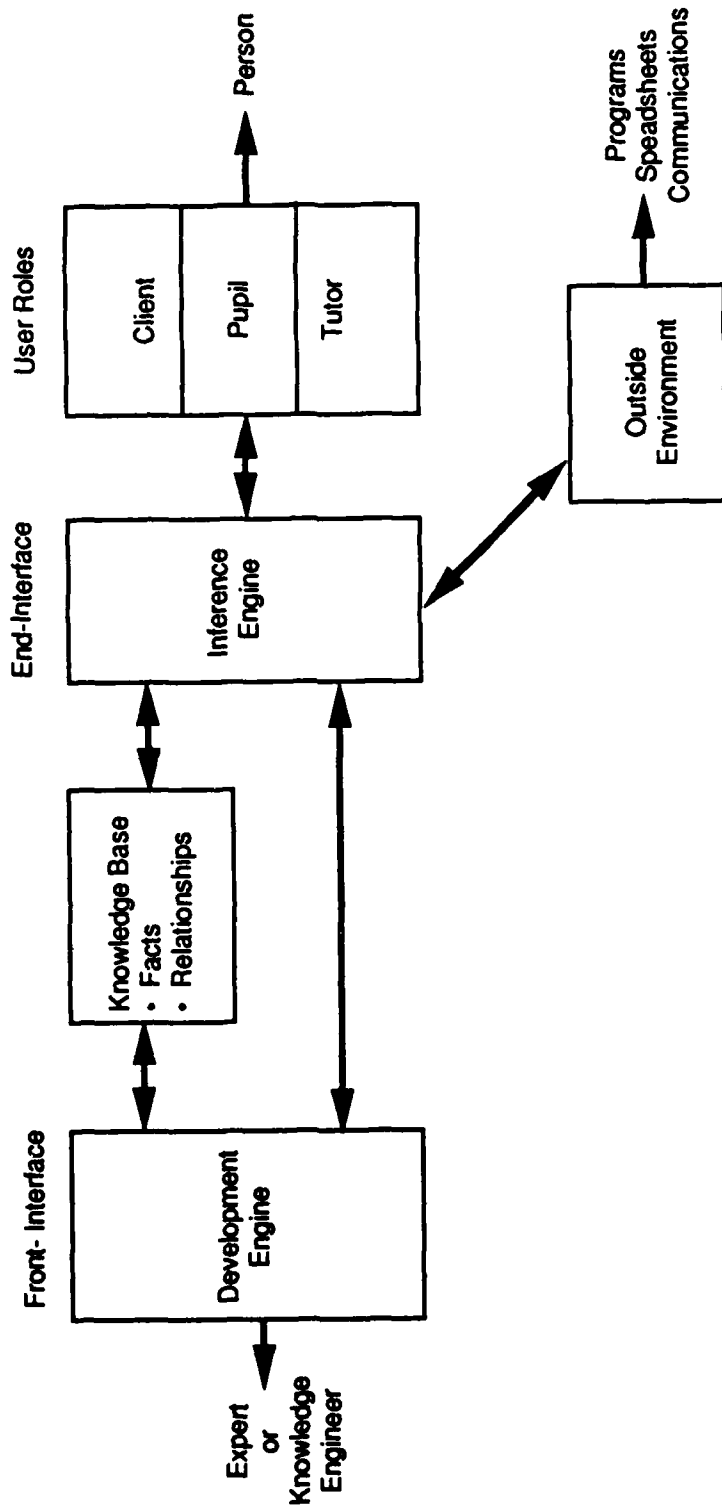


Figure 1

Basic Components of an Expert System
(Wolfgram and others, 1987: 13)

the reasoning and justification behind each step of the process. An explanation facility allows the user to derive deeper understanding into the subject in question as well as gain confidence in the system (Maher, 1987: 7, 24).

Development of expert systems is possible in many different programming environments. The expert system can be directly coded into structured computer languages such as C, FORTRAN, or Pascal or into languages specifically developed for artificial intelligence such as LISP or PROLOG. Expert system development tools are also available to assist the knowledge engineer in development of the expert system. These tools speed the development by removing the drudgery and debugging associated with programming the development and inference engines (Maher, 1987: 15-18).

Benefits. Expert systems have a number of benefits. First, as the expert system is developed, the underlying expert's knowledge is made apparent. "Hence a written record of the knowledge of a domain is frequently made available for the first time" (Allen, 1986: 22).

Second, expert systems do not forget relevant factors under stress or in a time-critical situation, thus yielding greater consistency over human decision makers. Expert systems are impartial, giving "the same answer to beggars and kings" (Sell, 1985: 15). Weak decisions made on the basis of politics or partiality are avoided. Expert systems are also unaffected by the time of day, and do not "suffer from Monday morning blues or Friday afternoon impatience" (Sell, 1985: 15, Allen, 1986: 22).

Large quantities of details and tedious tasks are difficult even for the most experienced expert. To help an expert, an expert system "can

assimilate huge amounts of data and examine a large number of related factors simultaneously" (McCain, 1987: 9). Also, as the methodologies for solving the problems change, an expert system can "quickly assimilate new information and apply the information to aid management in the decision-making process" (McCain, 1987: 9).

Expert systems will also help middle managers to perform their work. "During the last few years, training developers have learned to make a sharp distinction between knowledge a performer needs to memorize and knowledge a person can access by means of a job or decision aid" (Harmon and King, 1985: 219-220). Many decisions learned and made by middle managers do not require memorization of the expertise, only familiarity with the concepts and the system. Expert systems can relieve the middle managers from the tedium of knowing vast amounts of details required for their jobs and free them for more productive tasks (Harmon and King, 1985: 219-220).

Drawbacks. Expert systems do have certain drawbacks which limit their applicability. Once designed, an expert system is not as creative as a human would be. "Human experts handle unexpected events by using imaginative and novel approaches to problem solving, including drawing analogies to situations in completely different domains. Programs have had little success doing this" (Waterman, 1986: 14).

Human experts gain much of their information directly through the use of their physical senses. For computers to "view" the data, the information must be translated into symbols understood by the computer. Information is sometimes lost in translation, possibly constraining the computer's range of solutions. Because of computers limited sensory

abilities, experts systems are generally limited to problem areas dealing with cognitive or reasoning skills only (Waterman, 1986: 14).

Humans generally have what is termed "commonsense."

Commonsense is a broad area of knowledge about the world and how it works. Commonsense knowledge encompasses a great deal of information which would be very difficult to include in an expert system. It also tells us what we do not know. An expert system might try in a futile effort to answer a question there is no solution for, or worse yet, pose an impossible solution to an unsuspecting user. An expert system's advice and counsel should not stand alone, but be tempered with human judgement (Waterman, 1986: 15).

Examples. Many different types of systems are being prototyped and tested. Included in this section are several examples of systems being anticipated currently.

DSCAS. The Differing Site Condition Analysis System models a lawyer's decision process in analyzing a contractor's claim of a differing site condition. A differing site condition generally refers to a situation costing the contractor additional time and effort that he could not have foreseen. Approximately 20% of the contract modifications issued by the Air Force are attributed to differing site conditions (Osgood, 1988). Often, claims are settled long after the completion of the work, because of the intense and complex coordination required. The program is intended to provide contract administrators job site access to the legal expertise needed in clarifying the claims. The user steps through a series of 22 modules considering such elements as the claim's timeliness, evaluating express-implied contract conditions, and determining superior knowledge. By

providing the legal expertise on site, the contract administrators can decide whether the claim has merit and whether or not to negotiate (Kruppenbacher, 1984: 2-3, 151).

Inactive Hazardous Waste Site Characterization. This system uses the U.S. Environmental Protection Agency's Hazard Ranking System (HRS) to rank hazardous waste sites. The HRS ranks the potential hazard of the sites in three categories; (1) migration of pollutants through groundwater, surface water, and air, (2) explosion and fire potential, and (3) direct contact with hazardous pollutants. Data inputs include such items as the soil permeability, soil stratification, groundwater flow, and gradient. The system produces a HRS score for site permeability and groundwater flow (Law, 1986: 159-166).

Construction Schedule Analysis. This system provides an analysis and evaluation of a construction schedule from the facility's owner perspective. Data used for the analysis is gathered from the project management system (PRIMAVERA™) and the database management system (dBaseIII™) using an expert system shell. As construction progresses and the schedule is revised, the system evaluates the schedule in a number of areas. For example, built-up roofing should not be scheduled during winter months because the outside air temperatures are expected below the minimum required. The system also notes higher/lower production rates than anticipated and identifies other activities effected (O'Connor, 1986: 67-71).

Expert System Development

Expert system builders don't have a series of well defined steps that they follow when constructing a system. The inherent complexity of the system building process precludes laying out all the steps in advance. As a result, system builders have found that an evolutionary development style is the most effective way to proceed [Waterman, 1986: 135].

Three development processes are described in this section. The Hayes-Roth scheme shows a classical development of an expert system. Harmon and King provide the element of scale in their two expert system developments, detailing both a large scale and small scale development scheme.

Hayes-Roth. The evolution of an expert system involves several stages including identification, conceptualization, formalization, implementation, testing, and finally the prototype revision. Figure 2 shows the progression of the stages.

Identification Stage. During this stage, the problem is explored from several different aspects. The participants (experts and knowledge engineers) are selected and their roles in the development effort are defined. The domain expert and the knowledge engineer attempt to characterize the problem. The terms for the project are clarified and key concepts delineated through repeated interaction between the knowledge

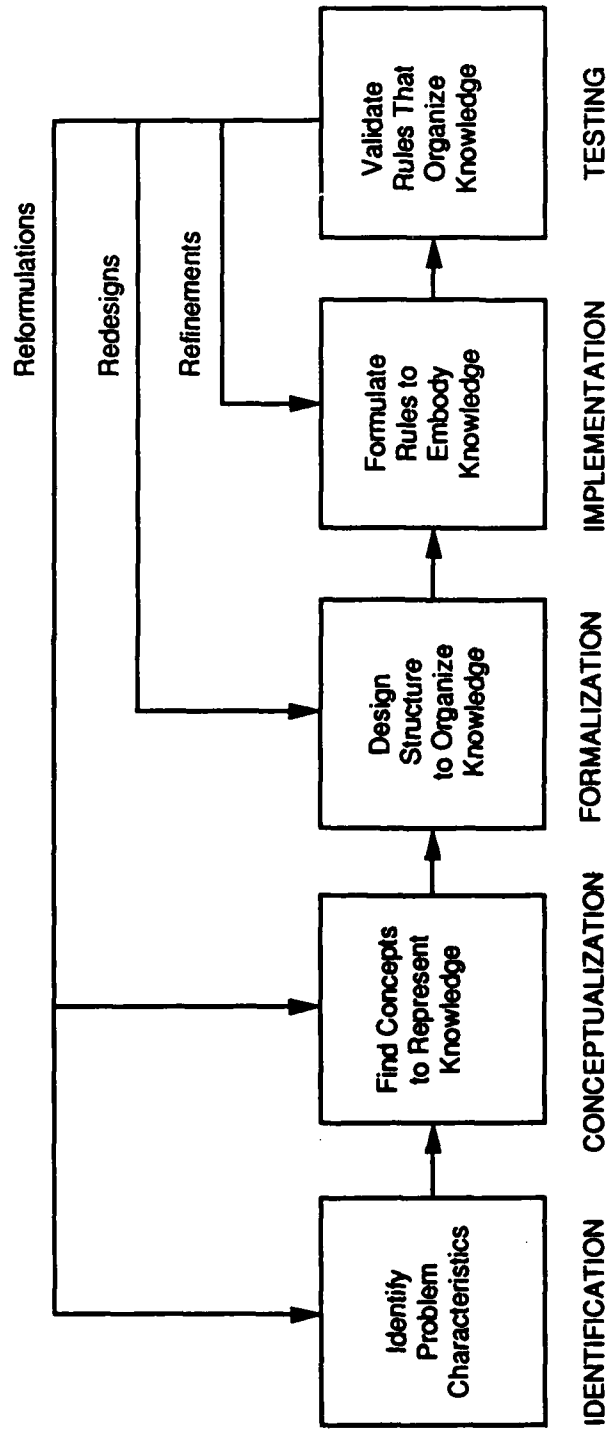


Figure 2
Stages of Knowledge Acquisition
(Hayes-Roth and others, 1983: 139)

engineer and the domain expert. Resources such as computers, funding, and time of the domain expert and knowledge engineer, are considered and allocated. The system goals are set forth (Hayes-Roth and others, 1983: 104-143).

Conceptualization Stage. Key concepts and relations are made explicit under this stage by continued interaction between the domain expert and the knowledge engineer. The knowledge engineer may start building a prototype to test the concepts delineated by the domain expert. Specific examples are used to challenge the system. The knowledge engineer may also elect not to show the system to the domain expert for fear of interfering with the next stage, formalization (Hayes-Roth and others, 1983: 143-144).

Formalization Stage. The formalization stage converts the key concepts, subproblems, and information flow characteristics into formal representations. Formalizing the concepts determines how the expert system will generate hypotheses. A knowledge-engineering tool or framework is selected for the prototype (Hayes-Roth and others, 1983: 144-146).

Implementation Stage. The formalized knowledge is mapped into the representational framework. Inconsistencies in the system are worked out. The end product is an expert system prototype ready for testing (Hayes-Roth and others, 1983: 144-147).

Testing Stage. The testing stage evaluates the system. Two or three typical cases are run through the system to assure its performance. Then atypical cases are used to challenge the system to make the strengths and weaknesses of the program become more apparent. Ultimately, the

program is assessed in light of the original goals and judged to be either adequate or inadequate (Hayes-Roth and others, 1983: 147-148).

Prototype Revision. The expert system is constantly revised and altered during the building process. This revision process does not end with an adequate prototype but continues with refinements, redesigns, and reformulations of the implemented system. "The result of revision should be a convergence of performance, once the expert system's scope of reasoning has been stabilized" (Hayes-Roth and others, 1983: 149). If the performance does not converge, then more drastic revisions may be necessary (Hayes-Roth and others, 1983: 148-149).

Harmon and King. Harmon and King add the dimension of size to their view of the development process. At one end of the spectrum are large-scale systems encompassing 2000 or more rules. At the other end of the spectrum are small-scale systems with 100 to 500 rules. Harmon and King advocate different development schemes for each end of the spectrum (Harmon and King, 1985, 228).

Large-Scale Knowledge System Development. Harmon and King see large-scale knowledge system development as a team effort incorporating a knowledge engineer and the domain expert similar to Hayes-Roth scheme. They suggest a slightly different development path, presented in phases:

- | | |
|------------|--|
| Phase I. | Selection of an Appropriate Problem. |
| Phase II. | Development of a Prototype System. |
| Phase III. | Development of a Complete Expert System. |
| Phase IV. | Evaluation of the System. |
| Phase V. | Integration of the System. |
| Phase VI. | Maintenance of the System. |

Phase I - Selection of an Appropriate Problem. In this phase, the problem domain and task are clearly identified. "Large-scale systems, because of the very large initial development costs, must necessarily focus on problems that are carefully selected to assure a large and rapid payback for their developers" (Harmon and King, 1985: 197). The expert must be identified and willing to provide the expertise. A tentative approach to the problem is formulated, along with a cost and benefits analysis. Before moving on to the next phase, a specific plan is proposed to guide the development of the system (Harmon and King, 1985: 197-201).

Phase II - Development of a Prototype System. The knowledge engineer accomplishes a series of tasks to develop the prototype. Initially, the knowledge engineer gathers information about the domain and the task. The expert provides four or five typical cases for the system to solve. The knowledge engineer works through the cases with the expert, learning the problem solving strategies and heuristics related. From this information, the knowledge engineer creates a prototype. Performance criteria for evaluating the prototype is established. The knowledge engineer and the expert jointly test the prototype using a variety of cases. The knowledge engineer and the expert revise and modify the system until it is functioning satisfactorily. The knowledge engineer then develops a detailed design for the complete system (Harmon and King, 1985: 201-203).

Phase III - Development of a Complete Expert System. At this point, the knowledge engineer may consider discarding the prototype in favor of rethinking the design. By rethinking the design, economies of effort can be realized for both the user of the system and the

system itself. Also, additional heuristics, developed as rules, are added to deal with the subtler aspects of certain problems. The interface is tailored to be easy and natural for the user by providing explanations or defining the terms of the system (Harmon and King, 1985: 203-205).

Phase IV - Evaluation of the System. The expert and knowledge engineer field test the completed expert system against the performance criteria established in Phase II. Other experts view the system and challenge it with examples of their own (Harmon and King, 1985: 205).

Phase V - Integration of the System. During this phase, the system is integrated into the work environment. Users are trained on how to use the system and with develop confidence in the system. The knowledge engineer fades from the picture during this phase (Harmon and King, 1985: 205-206).

Phase VI - Maintenance of the System. As the knowledge and expertise for accomplishing the job of the expert system change, the system must be updated and kept current. If the modifications are simple enough and the system is friendly enough, the expert or manager in charge of the system can make the changes (Harmon and King, 1985: 206-207).

Small-Scale Knowledge System Development. The small-scale knowledge system as envisioned by Harmon and King is different from the concepts presented so far.

Many American companies are attempting to reduce their layers of middle managers. . . . Expert systems will probably be developed to assist middle managers who are being asked to monitor a large and increasing volume of

information. The systems will help gather and rearrange the information. Moreover, they will provide managers with tools that will help them explore the implications of fast-breaking developments. Such managerial systems, probably packaged into managerial workstations, may begin to appear in large corporations within the next five years [Harmon and King, 1985: 216].

Not only will the systems be used by middle management, in many cases, the knowledge systems will be developed by middle management.

Our own view is that small knowledge system building tools can and will be used by middle managers and training developers to solve a vast array of small irksome problems. The individuals using these tools will not be "knowledge engineers" but will, instead, be people who are close to the problems. Senior application examiners will develop small knowledge systems that will provide assistance to clerical personnel [Harmon and King, 1985: 178].

Harmon and King describe a modified development path for the smaller system in steps (shown in Table 2). While the steps are similar to the two previous schemes presented, the knowledge engineer's job has essentially been replaced by the expert and the tool or shell used to derive the expert system. Knowledge systems will be created by individuals that are actually using them, with a minimum of training. These knowledge systems will move some simpler decisions to lower levels, giving middle managers more time for complex and crucial decisions (Harmon and King, 1985: 194).

Table 2

DEVELOPING A SMALL KNOWLEDGE SYSTEM

Step 1	Select a tool and implicitly commit yourself to a particular consultation paradigm.
Step 2	Identify a problem and then analyze the knowledge to be included in the system
Step 3	Design the system. Initially this involves describing the system on paper. It typically involves making flow diagrams and matrices and drafting a few rules.
Step 4	Develop a prototype of the system using the tool. This involves actually creating the knowledge base and testing it by running a number of consultations.
Step 5	Expand, test, and revise the system until it does what you want it to do.
Step 6	Maintain and update the systems needed.

(Harmon & King, 1985: 178)

Moreover, we think their appearance will be welcomed in the same way that managers welcomed electronic spreadsheet programs. Individuals throughout large organizations will begin to document the knowledge that is actually used to get the job done [Harmon and King, 1985: 194].

Ultimately, Harmon and King see the small systems as a way for organizations to build confidence in constructing and using expert systems. Developing small systems initially avoids the very large development costs, but verifies the concept of an expert system to the organization (Harmon and King, 1985: 197).

Problem Selection

All of the different development schemes involve considerable time and effort, which point to the importance of proper problem selection. "The choosing of the domain is a critical task in the development of an expert system" (Prerau, 1985: 26).

The selection criteria of the problem area for expert system development gives tremendous insight into expert systems. The capabilities and limitations of systems can be seen clearly. Novices can learn from different the selection criteria to develop proper expectations for using expert systems.

Waterman. Waterman suggests considering three main areas before selecting a problem to be developed into an expert system. "Consider expert systems only if expert system development is possible, justified, and appropriate" (Waterman, 1986: 127).

Possible. In considering a problem area, Waterman lists eight different requirements that must all be met to make expert system development possible, shown in Figure 3. "One of the most important requirements is that genuine experts exist" (Waterman, 1986: 128). If genuine experts do not exist, the system will be difficult, at best, to develop. Beyond having genuine experts, the experts must agree on the solutions and be able to articulate their methods for solving the problems. If the expert cannot sufficiently describe his technique, the knowledge will be difficult to extract and develop. Disagreement between the experts on major tenets of the problem and solutions will also impede system development (Waterman, 1986: 128-129).

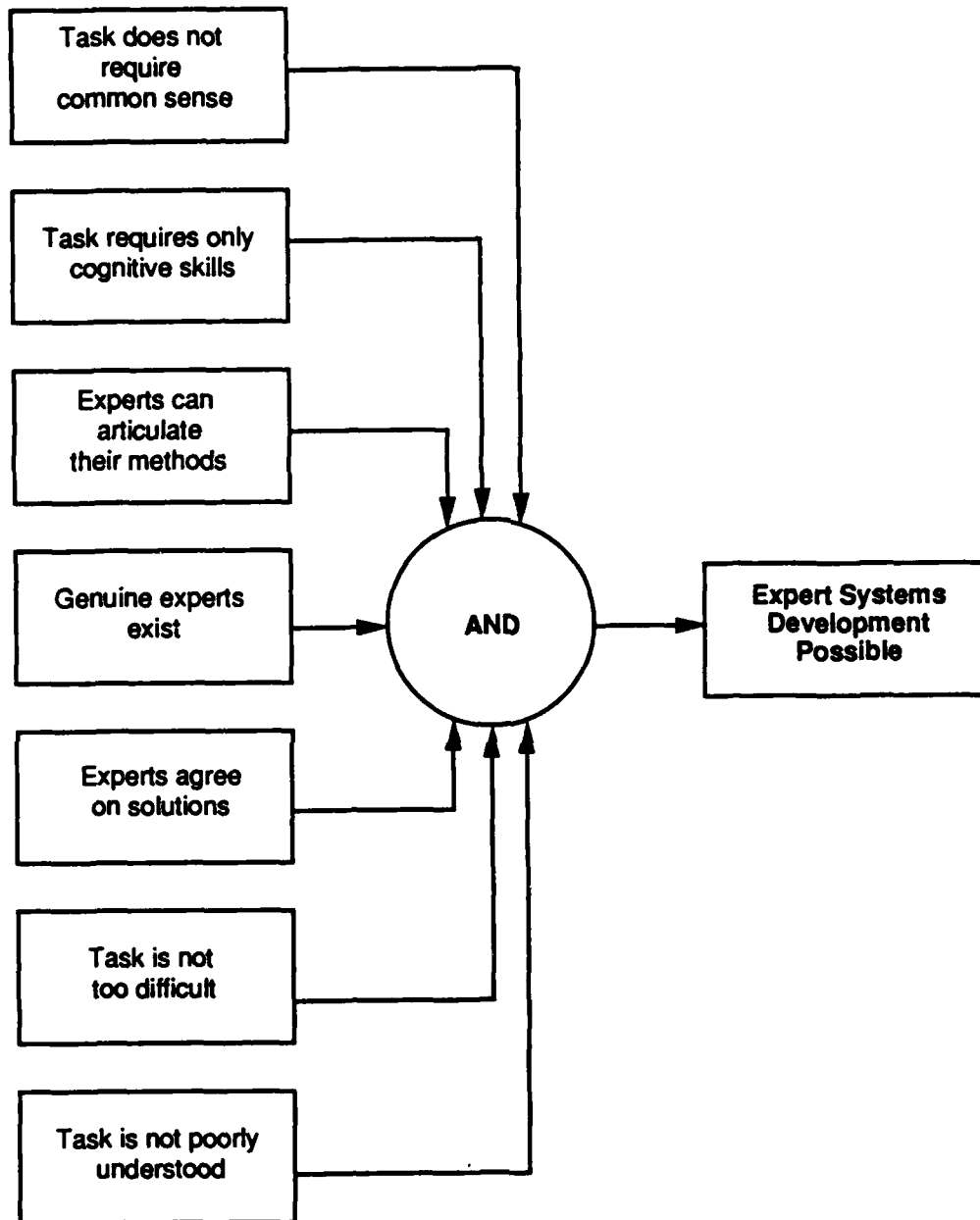


Figure 3

Necessary Requirements for Expert System Development
(Waterman, 1986: 129)

Waterman also considers the requirements for solving the task. The task must use reasoning, or cognitive skills only. Tasks requiring specialized sensory abilities, such as a wine connoisseur's refined ability to smell, would be difficult to develop into an expert system. Also, tasks requiring common sense beyond the user's ability present an impediment to development (Waterman, 1986: 128).

In general, the task must not be too difficult. If an expert cannot teach a novice the skill required for the task, it is unlikely that the expert could teach a computer. "Or if any expert takes days and weeks rather than hours to solve the problem, there's a good chance that it's too difficult or too complex for a knowledge engineering approach" (Waterman, 1986: 128). Complementing the expert's ability to articulate his methods, the task must be well understood. "If the task is so new or poorly understood that it requires basic research to find solutions, knowledge engineering will not work" (Waterman, 1986: 128-129).

Justified. Any one of several situations can justify the effort and expense of developing an expert system, as shown in Figure 4. If a task has a very high payoff, an organization can justify an expert system development. The payoff can be in either time or money. Another situation is where human expertise is being lost to retirement or personnel changes. An expert system could be used to capture the expertise and retain for future use as well as distributing the knowledge to where it is needed (Waterman, 1986: 130-131).

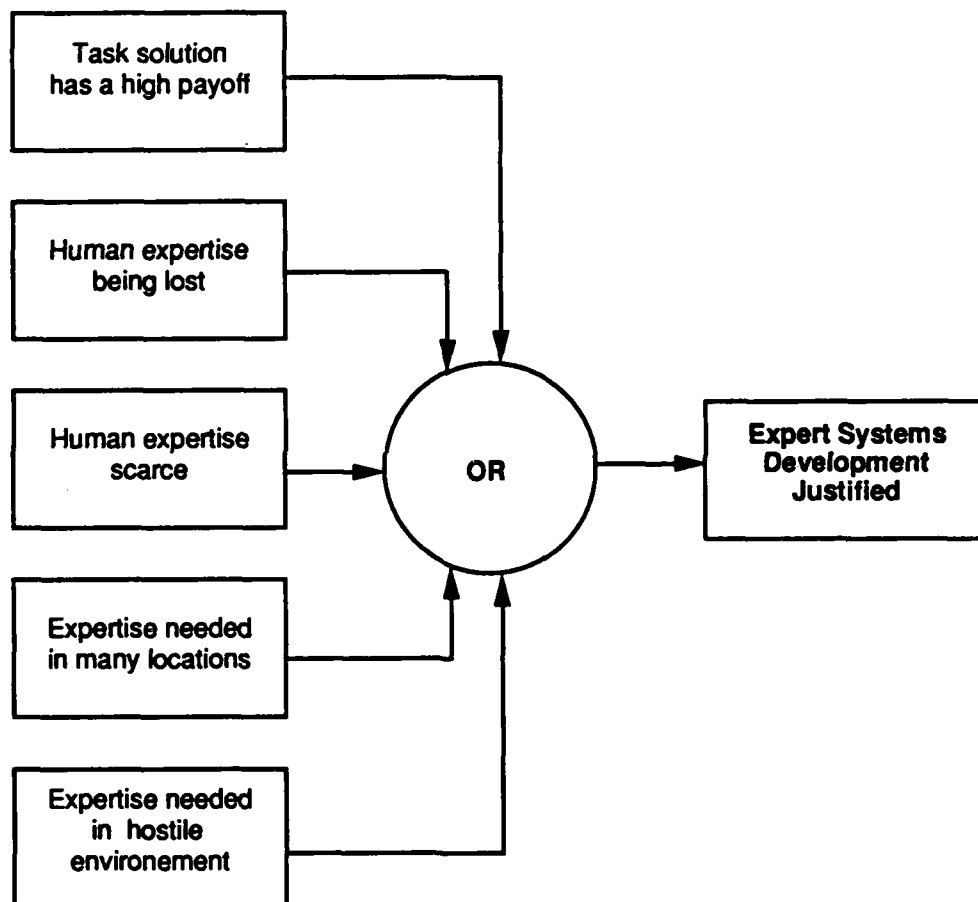


Figure 4

Justification for Expert System Development
(Waterman, 1986: 130)

An expert system development is justified when the expertise is scarce or needed at many different locations at the same time.

The problem is compounded when the company needs similar expertise at many different locations, such as process control expertise for each distillation column owned by a petrochemical plant. This generates a need for multiple versions of the expert, something that can be done easily and at virtually no cost when the expert is a computer program [Waterman, 1986: 131].

Lastly, an expert system development is justified when the expert is needed in hostile or unfriendly environment. Using an expert system in a hostile situation risks the system and not the expert (Waterman, 1986: 131).

Appropriate. Three factors must be met in deciding whether a problem area is appropriate: nature of the area, the complexity of the area, and the scope of the problem to be addressed by the expert system. Figure 5 shows these characteristics.

Nature. Problems most appropriate for expert system development are heuristic in nature. Heuristic problems use strategies and rules of thumb to achieve acceptable solutions. Mathematically intense algorithms, yielding the optimum solutions, would not be good candidates for expert systems.

In some sense, the expert systems approach is the last resort. If the problem can be solved mathematically or with clever algorithms, then those methods should be used. If it's too difficult for these conventional techniques, expert systems may be appropriate [Waterman, 1986: 132].

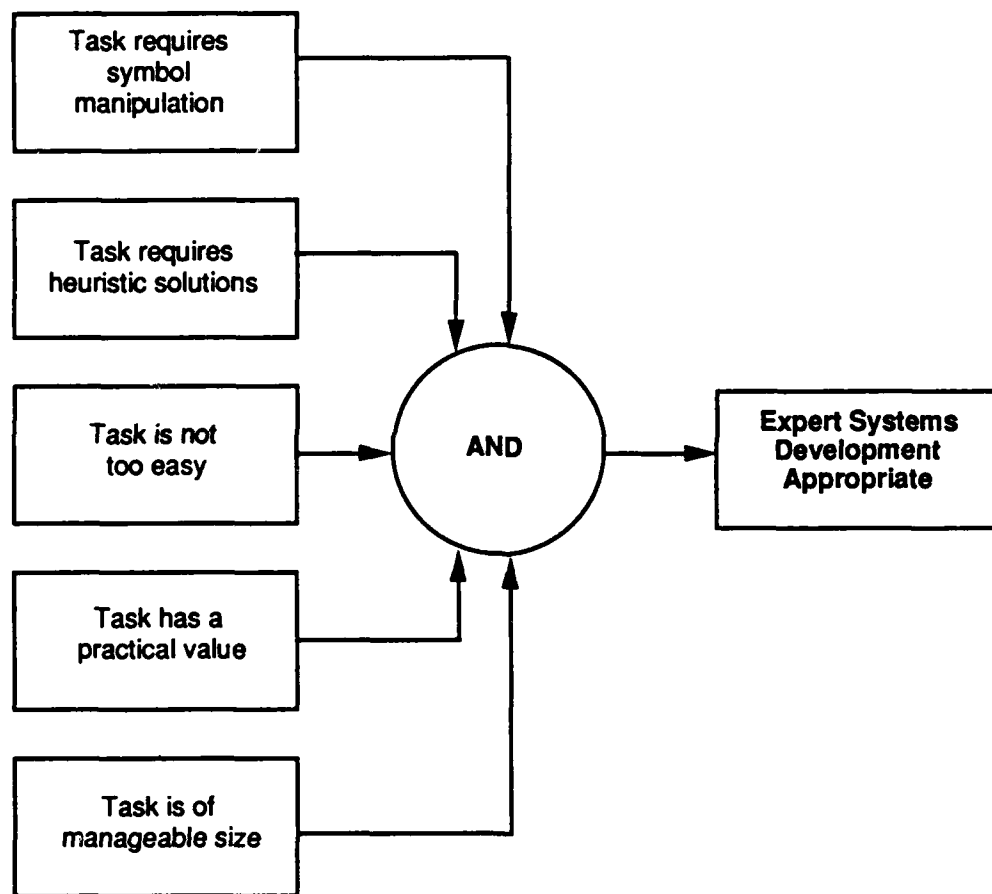


Figure 5

Characteristics Appropriate to Expert System Development
(Waterman, 1986: 132)

Complexity. The problem addressed by the expert system should not be too easy. Much effort and time are required to develop an expert system. If an easy problem is selected, then the users may quickly learn the heuristics and disregard the system. Unless the intent of the building the system is for training, a more complex problem should normally be considered (Waterman, 1986: 132).

Scope. The scope of the problem needs to be defined in terms of practical value and manageable size.

It should be sufficiently narrow to make the problem manageable and sufficiently broad to ensure that the problem has some practical interest. Unfortunately, the definitions of manageable and practical depend on the particular problem domain. And to make matters worse, choosing the proper scope is crucial to the success of the expert system endeavor [Waterman, 1986: 133].

Typically, the knowledge engineer divides a large problem down into parts until the area to be developed is a manageable size, but still has a practical value (Waterman, 1986: 133-134).

Cross. Artificial intelligence is viewed by many as being some sort of science fiction or managerial panacea. A myriad of expectations develop when artificial intelligence is discussed. User's and expert's expectations of expert systems are often unrealistic (Cross, 1988).

Solutions. Managers and experts frequently expect expert systems to solve problems that cannot be solved now. Unfortunately, this is not the case. Unless an expert can solve the problem, an expert system will

not be of assistance. The current state of expert system development is dependent on reviewing cases of situations that have been solved to develop the system. If no satisfactory solutions have been obtained up to this point in time, the most an expert system development might contribute is a clarification of the problem solving technique or methodology (Cross, 1988).

Volatility. Because of the time and effort needed to modify an expert system, the knowledge area being developed needs to be fairly mature and closer to static than dynamic. If major changes are being made in the techniques for solving problems, an expert system would be difficult to develop. One way to determine the volatility of the knowledge area is to look back three to five years and compare the technology for solving the problems at that time with those of the present. If major changes have been made in the recent past, changes may also be projected for the near future (Cross, 1988).

Prerau. David Prerau presents a very good methodology in his article "Selection of an Appropriate Domain of an Expert System." Many of Waterman's salient points are covered, but organized in a different fashion:

- Basic Requirements
- Type of Problem
- The Expert
- Problem Bounds
- Domain Area Personnel - Users
- Other Desirable Features

The article includes other crucial points that must be considered before embarking on an expert system development. Prerau's selection criteria is in Appendix A (Prerau, 1985: 28).

Commitment. Before starting on the development of an expert system, Prerau suggests soliciting and establishing support for the effort. Foremost, senior management must commit resources and time to see the project through development. Also, the expert must be committed to the development of the project. If any of the participants waver, the development effort may flounder and the expert system may be weak and nearly useless (Prerau, 1985: 28-29).

User support must also be solicited and nurtured. An expert system has little benefit unless used. Realistic user expectations of the systems utility and capability need to be cultivated. The users need to understand that "even a successful system will likely be limited in scope, and like a human expert, may not produce optimal or correct results 100% of the time" (Prerau, 1985: 28). During the development of the expert system, the users need to be consulted to ensure that the domain and the scope of the system have utility for them (Prerau, 1985: 28-29).

Political Sensitivity. Prerau also suggests considering the political sensitivity toward the development of an expert system within an organization. "For example, there may be certain practice, embodied in heuristics, which may prove embarrassing if written down, such as how certain customers are treated relative to other customers" (Prerau, 1985: 29). Factions within the organization may also challenge the system if it does not produce results that favor them politically. If a expert system's intent is to allocate funds to acquire resources, the validity of the system may constantly be challenged (Prerau, 1985: 29).

Statement of the Problem

The problem is, simply stated, "How can Air Force Civil Engineers use expert systems?" To answer the question, ideas must be gathered and compared with a criteria to select the viable options. The ideas will be solicited from experienced civil engineers and evaluated with their assistance. Those providing the ideas, though they might have a tacit interest in the subject, will most likely be under the crush of other impending work. Hence, the criteria used to filter the ideas must not only be complete, but also succinct. This thesis creates a methodology for screening potential ideas, and selecting justified, appropriate, and possible ideas.

Prerau's selection criteria, though very complete, is also very long containing 53 questions. Many of the questions concern soliciting or confirming commitment by all parties involved, prior to the final commitment of resources. While Prerau's methodology is appropriate before making the last step, it would be difficult to employ in preliminary survey searching for ideas and proposals.

The methodology this thesis developed is a modification of Waterman's selection criteria. Waterman's criteria will be used in total, but reordered with the most discriminating questions first, to eliminate unviable ideas quickly. Also, additional discriminating questions from other selection criteria will be added when appropriate.

III. Methodology

Overview

This chapter discusses the methodology underlying this thesis. Included in this chapter are sections covering why interviewing was chosen versus written survey to identify ideas, how the structured questionnaire was derived, how the interviews were conducted, and how the analysis and conclusions will be presented.

Why Interviewing?

The researcher interviewed experienced civil engineers to gather ideas for possible development into expert systems. Interviewing provided a means of interacting with the expert, to clarify and further develop information supplied by the interviewee. Because of the relative newness of the field, those being interviewed were unfamiliar with expert systems and their capabilities. A personal interview created the opportunity to respond to the interviewee's questions firsthand.

Interviewing does have several drawbacks. Because of the time it takes to accomplish an interview, a fewer number of interviews can be accomplished in the same time that it would take to complete written surveys. Also, the interview is generally limited to a certain block of time; whereas, a survey could be read, thought about, and then accomplished at a later time.

The benefits of interviewing outweigh its drawbacks. Interviewing commits both the interviewee and the researcher to spending adequate time on the subject and providing a better quality of information than a written

survey. Furthermore, interviewing offers an opportunity to approach the problem from the interviewee's point of view and is not limited to the researcher perspective. Ultimately, the goal of this thesis is to gather new ideas, and interviewing offers the best means of accomplishing that goal (Davis, 1987).

Research Methodology

The research methodology has been divided into seven steps: (1) familiarization with expert systems, (2) development of the selection criteria, (3) the first round of interviewing, (4) compilation the ideas, (5) the second round of interviewing, (6) results and findings, and (7) recommendations on the selection criteria.

Step 1 - Familiarization with Expert Systems. The researcher became familiar with expert systems, their development, and several problem selection criteria. The familiarization was accomplished by a literature review and discussion with experts in the field of expert systems.

Step 2 - Development Selection Criteria. When interviewing top-level managers, time is at a premium. The objective was to minimize the time taken to accomplish the survey, while still attempting to obtain as many ideas as possible. To meet this objective, the questions were ordered with the most discriminating questions first. By ordering the interview this way, ideas with low potential for expert system development were dropped as soon as possible.

The underlying basis for this research's selection criteria was Waterman's methodology. Waterman's methodology was supplemented by inputs from Cross and Prerau. Figure 6 graphically shows the selection

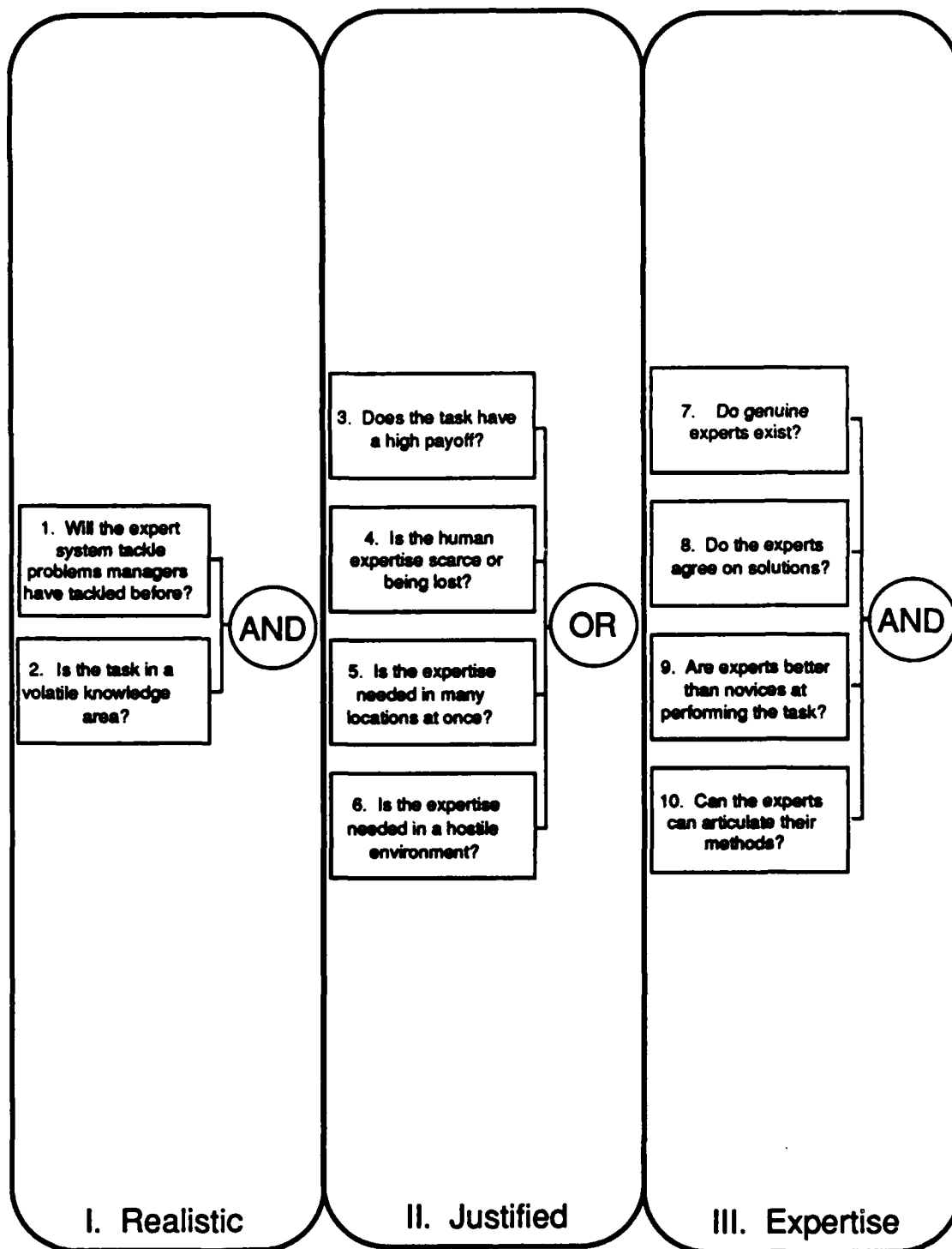


Figure 6
Preliminary Selection Criteria

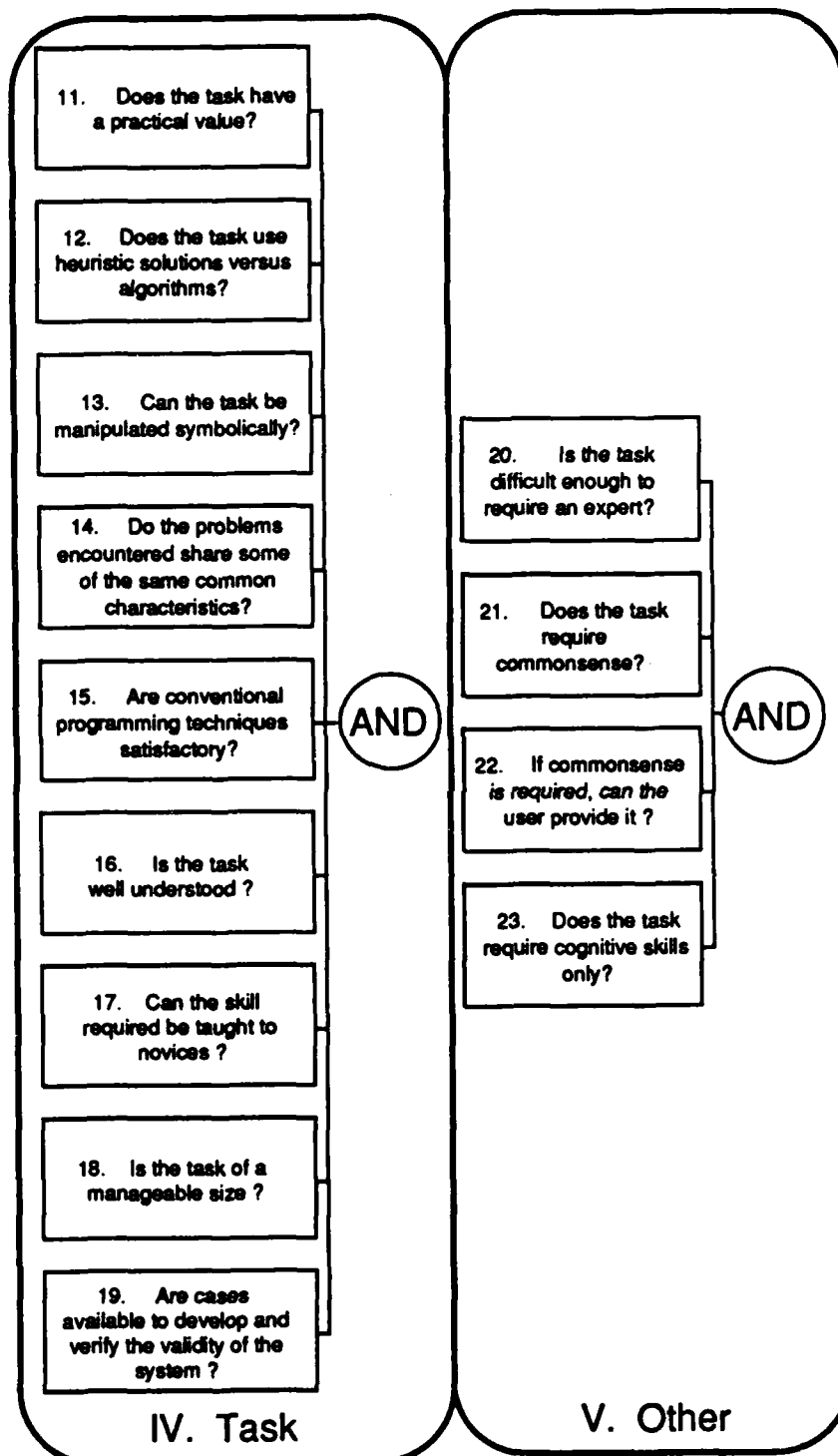


Figure 6 - continued
Preliminary Selection Criteria

criteria, which is also described in Appendix C. All the questions in the selection criteria were conceived to be answered either 'yes' or 'no'.

Waterman. Waterman's selection criteria was used in total.

The appropriate and possible sections were distributed across the expertise, task, and other consideration sections of the selection criteria. The justified section was left in tact, except that the concerns about expertise being lost and scarce will be combined into Question 4 (Waterman, 1986: 127-129).

Cross. The first two questions in the selection criteria were derived from Cross' considerations of a problem having a solution and concerning the volatility of the knowledge area being explored. These were considered the most discriminating questions. Cross also contributed Question 14, "Do the problems encountered share some of the same common characteristics?" (Cross, 1988).

Prerau. A number of questions were drawn from Prerau's selection criteria that either amplified certain points or filled in possible gaps. For example, Question 9 "Are experts better than novices at performing the task?" amplifies Question 7 "Do genuine expert exist?" If experts are no better than novices, it is difficult to declare that genuine experts exist (Prerau, 1985: 26-30).

The question order in the selection criteria was developed from interviews with Major Stephen Cross and Major James Holt. The first section, thought to be the most discriminating, was whether the ideas proposed were realistic or not. The next most discriminating section was the justification of the idea, with the experts, task and other considerations sections following. Selection criteria was tested against a surrogate interviewee as to insure consistency (Cross, 1988, Holt, 1988).

Step 3 - First Round of Interviews. Eight experienced military civil engineers were selected to be interviewed. This group was chosen on the basis of their experience in civil engineering. The number of individuals was limited by the time available to the researcher. The individuals chosen are listed in Appendix B.

Before starting the questioning, the interviewees were shown a simple expert system called the "Wine Advisor" (Giarratano, 1987). The interviewees were requested to think of a meal they would have wine with, and the expert system assisted them in selecting a wine. The system demonstrated to the interviewees the capabilities of an expert system first-hand. A brief background of expert systems was discussed and several examples were presented.

Initially, background information was exchanged to acquaint both the researcher and interviewee with each other. The interviewee then selected a problem area within civil engineering for expert system application. The questioning and discussion continued through the first idea, regardless of its potential. By reviewing all the questions with the first idea, the interviewee became more familiar with the types of questions and would be more discriminating of the ideas he suggested after the first idea. Starting with the second idea proposed, ideas were eliminated by more than one unacceptable response. It was hoped that each interviewee could supply five ideas to be run through the problem selection process, though the limits of time were understood.

Step 4 - Compiling the Ideas. After the interviews were completed, the ideas were compiled into a master listing of proposals. Similar ideas, if any, were grouped together into single proposals. The

master listing will be reviewed by the interviewees for their inputs in Step 5. None of the proposals were attributed to their contributing interviewee, so other interviewees selection of a proposal was based purely on the proposal's merit. Also, interviewees were not allowed to select their own proposals, unless their idea was shared with another interviewee. The intent of this limitation was to eliminate each of the interviewees selecting only their proposals.

Step 5 - Second Round of Interviews. The interviewees were requested to select five proposals. Their selections were based on their experience and in their view, which proposals would benefit Air Force Civil Engineering the most. Those selections were then rank ordered.

Step 6 - Results and Findings. The selections of interviewee were weighted as follows:

<u>Priority</u>	<u>Weight</u>
1	5 points
2	4 points
3	3 points
4	2 points
5	1 points

The five selections with the heaviest weightings are described more fully in Chapter 4 and recommended for consideration of development into expert systems. The descriptions have been expanded from the information gathered during the interviews.

Step 7 - Recommendations on Methodology. Recommendations for changes and improvement in the methodology are suggested in Chapter 5 of this thesis.

IV. Results and Findings

Overview

This chapter presents the ideas collected through the first round of interviews using the selection criteria and the findings of the second round selections.

First Round Ideas

Interviews. Eight experienced managers in Air Force Civil Engineering were interviewed in accordance with Step 3 in the research methodology. The list of interviewees is in Appendix D. Twenty-one ideas were collected from the interviewees. A summary of the ideas collected is presented in Table 3. The raw data collected, 'yes'/'no'/'maybe' answers to each of the questions in the selection methodology, is listed in Appendix E.

Uncertainty. The original intent of the questions in the methodology was to elicit 'yes'/'no' responses from the interviewees. Some uncertainty was expected, but not quite on the scale experienced. The uncertainty was incorporated by allowing 'yes'/'no'/'maybe' responses. The uncertainty in the responses reflects of the initial nature of the preliminary screening process. As topics are selected and screened further using Prerau's selection criteria, involving experts and users alike, the uncertainty should be reduced (Prerau, 1985: 26-30).

Selection Criteria Applied. Ideas from the interviewees were only eliminated during the interviews if the underlying Waterman selection criteria or Cross' questions were violated. Because of the uncertainty

Idea	Proposed Expert System	Proposal	I Realistic	I Justified	III Expertise	IV Task	V Other
1	Classification of Repair	1	yes	yes	yes	yes	yes
2	Force Beddown at a Bare Base	2	yes	yes	yes	maybe(2)	yes
3	Selection of Minimum Operating Strip (MOS)	3	yes	yes	yes	maybe(1)	yes
4	Force Development/Force Structure	4	no	yes	maybe (2)	maybe (2)	yes
5	Facility Constraints on New Aircraft Designs	5	yes	yes	yes	maybe (2)	yes
6	Corrosion Control	6	yes	yes	yes	yes	yes
7	Tracking of Design Projects	7	yes	yes	maybe (1)	yes	yes
8	Allocating Vehicles	8	yes	yes	maybe (1)	yes	maybe (1)
9	Energy Management	9	yes	yes	yes	maybe (1)	yes
10	Design Schedule Management	7	yes	yes	yes	maybe (1)	yes
11	Work Order Management	10	yes	yes	yes	maybe (1)	maybe (1)
12	Paint Selector	6	maybe (1)	yes	yes	maybe (2)	yes
13	Well-Rounded People Advisor	11	yes	yes	maybe (1)	maybe (1)	maybe (1)
14	Prime BEEF - Priorities, Checklist, CPM	2	no	yes	yes	maybe (3)	maybe (1)
15	Maintenance of Liquid Fuel System	12	yes	yes	yes	maybe (1)	yes
16	Beddown of New Systems	13	yes	yes	maybe (2)	maybe (2)	yes
17	Bare Base Layout	2	yes	yes	yes	yes	yes
18	Job Order/Work Order Scheduling	10	yes	yes	yes	yes	yes
19	Tasking Mobility Forces/Force Structure	4	yes	yes	yes	no (1)	yes
20	Groundwater Decontamination	14	yes	yes	yes	maybe (2)	yes
21	Scheduling and Assignment of Engineers	15	yes	yes	yes	yes	maybe (1)

The number in the parentheses indicates the number of questions with "maybe" or "no" answers
e.g. maybe(2) indicates all yes with two "maybe" answers

Table 3

First Round Ideas

present, a broad interpretation was taken of the ideas collected in an effort to include all possibilities. Ideas offered by the interviewees were made into "proposals" for explanation in this chapter and use during the second round of interviews. Similar ideas were combined for presentation into single proposal.

Proposals

From the twenty-one ideas collected in the interviews, fifteen different proposals were derived.

1. Classification of Job Orders/Work Orders

Description. As conceived, this expert system would assist in classifying job orders and work orders per guidance provided by regulation and base policy. The system would be used by new clerks learning the process. Clerks typically make the initial classification of incoming job orders and work orders, subject to the approval of the section chief. More accurate initial classifications would ease the work load on the section chief. The expert system, by the training the clerk, would relieve the section chief further. The expert system could possibly be integrated into the existing civil engineering computer, WIMS (Work Information Management System) or the next generation of civil engineering computer systems .

Proposed by. One interviewee.

Selection Criteria. Met all the selection criteria.

2. Force Beddown at a Bare Base.

Description. This expert system would assist the civil engineers in bedding down aircraft and personnel at a bare base. The system would provide a flexible checklist that could be reordered to reflect

the priorities of the situation. The system might also include elements such as project scheduling, inventory control, and suggested layouts of base facilities to minimize damage from attacks.

Proposed by. Three interviewees.

Selection Criteria. Met all selection criteria with the following exceptions:

Realistic: The second interviewee thought the system was in a volatile knowledge area because of the changing requirements for Prime BEEF (Base Engineering Emergency Force).

Expertise: The second interviewee felt that experts may not come to agreement on all solutions.

Task: The first interviewee was unsure that the task could be manipulated symbolically. He felt there may be a lack of relevant test cases. The second interviewee saw each beddown operation as a separate situation, not sharing many characteristics. He also felt that the task is not well understood and may not be of a manageable size for an expert system.

Other: The second interviewee felt that the task may require skills other than cognitive.

3. Selection of a Minimum Operating Strip (MOS).

Description. This expert system would help civil engineers select the minimum operating strip (MOS) to launch and recover aircraft after a bomb attack. Data inputs to the system would include such items as locations of bomb damage and live ordnance. The system could be used during peacetime exercises to increase the proficiency of civil engineers as well as during wartime.

Proposed by. One interviewee.

Selection Criteria. Met all selection criteria with the following exception:

Task: Interviewee thought a conventional programming technique or computer aided design (CAD) might be easier to employ than an expert system.

4. Force Development/Force Structure.

Description. Under this premise, an expert system would be devised to structure civil engineering forces going to war. Such items as training levels and experience of units may be included in such a system. Once developed, the system would be used by headquarters to plan operations and exercises.

Proposed by. Two interviewees.

Selection Criteria. Met all selection criteria with the following exceptions:

Realistic: The first interviewee felt that the system may not be realistic because of recent changes in policy concerning the composition of Prime BEEF teams.

Expertise: The first interviewee felt no genuine experts may exist, and that if experts existed, they may not agree on the solutions.

Task: The first interviewee was also concerned the task may not be understood sufficiently to be developed into an expert system and may be beyond a manageable size. The second interviewee saw the process as more algorithmic than heuristic.

5. Facility Constraints on New Aircraft Designs.

Description. This expert system would delineate existing facility constraints to design managers of new aircraft systems. Constraints would include such items as facility dimensions, safe distance for munitions, and perhaps even long-range environmental effects. Financial impacts could be reflected in rough cost estimates to provide facilities for system that exceed the current facilities capacity.

Proposed by. One interviewee.

Selection Criteria. Met all selection criteria with the following exceptions:

Expertise: The interviewee was unsure all the experts would agree on the solutions presented by the system.

Task: The interviewee felt the system might actually be a combination of heuristics and algorithms. Also, the interviewee was unsure whether the task could be taught to novices, since many of the facility limitations are learned by experience.

6. Corrosion Control.

Description. A corrosion control expert system would advise users on inspection and maintenance of corrosive surfaces. Surface preparations and paint types would be identified depending on the material and use. The system could be updated periodically to reflect technological improvements available though different materials.

Proposed by. Two interviewees.

Selection Criteria. Met all selection criteria with the following exceptions:

Realistic: The second interviewee thought of technological improvements volatile enough to overcome developing an expert system.

Expertise: The second interviewee was uncertain whether all the experts would agree on the solutions to all problems.

Task: The second interviewee was unsure whether the task could be taught to novices or if it was of a manageable size.

Other: The first interviewee was uncertain that inspection could be totally classified as a cognitive skill.

7. Design Schedule Management.

Description. This expert system would assist in design schedule management. The system would be able to assess all the impacts of changes in schedules, priorities, and projects. The system could also include such checklist functions as assuring asbestos removal are considered during the design phase on existing facilities. The system could possibly encompass the programming process as well.

Proposed by. Two interviewees.

Selection Criteria. Met all selection criteria with the following exceptions:

Expertise: Both interviewees were unsure that the experts would all agree on the solutions presented by such a system.

Task: The second interviewee was uncertain the task of managing design was well understood.

8. Vehicle Allocation.

Description. A vehicle allocation expert system would be used by a vehicle officer within a civil engineering squadron to allocate vehicles.

Several different strategies might be available on such a system depending on location, mission, and vehicle availability.

Proposed by. One interviewee.

Selection Criteria. Met all selection criteria with the following exception:

Expertise: The interviewee was unsure whether genuine experts existed.

9. Energy Management.

Description. The expert system in this example would help the base energy management czar. The system would identify various strategies to employ conservation methods. The system could be updated periodically to include technological improvements.

Proposed by. One interviewee.

Selection Criteria. Met all selection criteria with the following exception:

Task: The interviewee was concerned the process might be more algorithmic than heuristic.

10. Job Order/Work Order Management.

Description. This expert system would interface with the WIMS database to improve the efficiency of scheduling and material ordering. Information from recent work could be compiled to provide production estimates and lead times on materials. The system could also suggest alternatives when problems are encountered in accomplishing scheduled work, such as listing another job in close proximity or scheduled maintenance.

Proposed by. Two interviewees.

Selection Criteria. Met all selection criteria with the following exceptions:

Task: The first interviewee thought there might be some conventional system that would fill the need as well as an expert system.

Other: The first interviewee thought that such an expert system might require skills beyond cognitive skills.

11. Well-Rounded People Advisor.

Description. This expert system would advise senior leadership on jobs and training for junior and mid-level managers. The system would gather data pertaining to the individual's background, education, and experience. The system would suggest a particular job and training to insure an individual was well-rounded. The system might be structured to handle people individually, or make recommendations for a group.

Proposed by. One interviewee.

Selection Criteria. Met all selection criteria with the following exceptions:

Expertise: The interviewee was unsure as to whether the experts would agree on how to make a well-rounded officer.

Task: The interviewee did not think the task was well understood nor could it be taught to novices.

12. Liquid Fuel System Maintenance.

Description. In this case, the expert system would train airman on the maintenance of liquid fuel systems. The system would also include

safety advisories and could possibly serve as a checklist prior to the start of maintenance.

Proposed by. One interviewee.

Selection Criteria. Met all selection criteria with the following exception:

Task: The interviewee thought the training process might be more algorithmic than heuristic.

13. Beddown of New Aircraft Systems.

Description. This expert system would be compiled from previous lessons-learned during the beddown of new aircraft systems. In the future, as new systems are bedded down, the system could be updated and revised to reflect the new lessons-learned.

Proposed by. One interviewee.

Selection Criteria. Met all selection criteria with the following exceptions:

Expertise: The interviewee was uncertain genuine experts exist and whether the experts could articulate their methods.

Task: The interviewee was also unsure whether the task was of a manageable size.

14. Groundwater Decontamination.

Description. This expert system would advise an engineer on the most effective pumping scheme for treating a contaminated aquifer.

Proposed by. One interviewee.

Selection Criteria. Met all selection criteria with the following exceptions:

Realistic: The interviewee felt that the knowledge area is in a state of flux.

Expertise: The interviewee was uncertain all of the experts would agree on common solutions.

Task: The interviewee was unsure about whether the task was well understood or if the skill could be taught to novices.

15. Scheduling and Assignment of Engineers.

Description. This expert system would advise managers on assigning engineers to design projects based on their current schedule, experience, and training. The system might also be expanded to other areas such as programming and construction management.

Proposed by. One interviewee.

Selection Criteria. Met all selection criteria with the following exception:

Other: The interviewee was uncertain whether the task is difficult enough to require an expert.

Second Round Selections

The eight interviewees were asked to review the fifteen proposed expert systems. Each of the interviewees were asked to select five proposals based on their experience in civil engineering. After making their selections, they were requested to prioritize the selections from one to five, with one being their top selection.

Points were assigned to each of the selections, per Step 6 in the research methodology. The results of the survey are compiled in Figure 7.

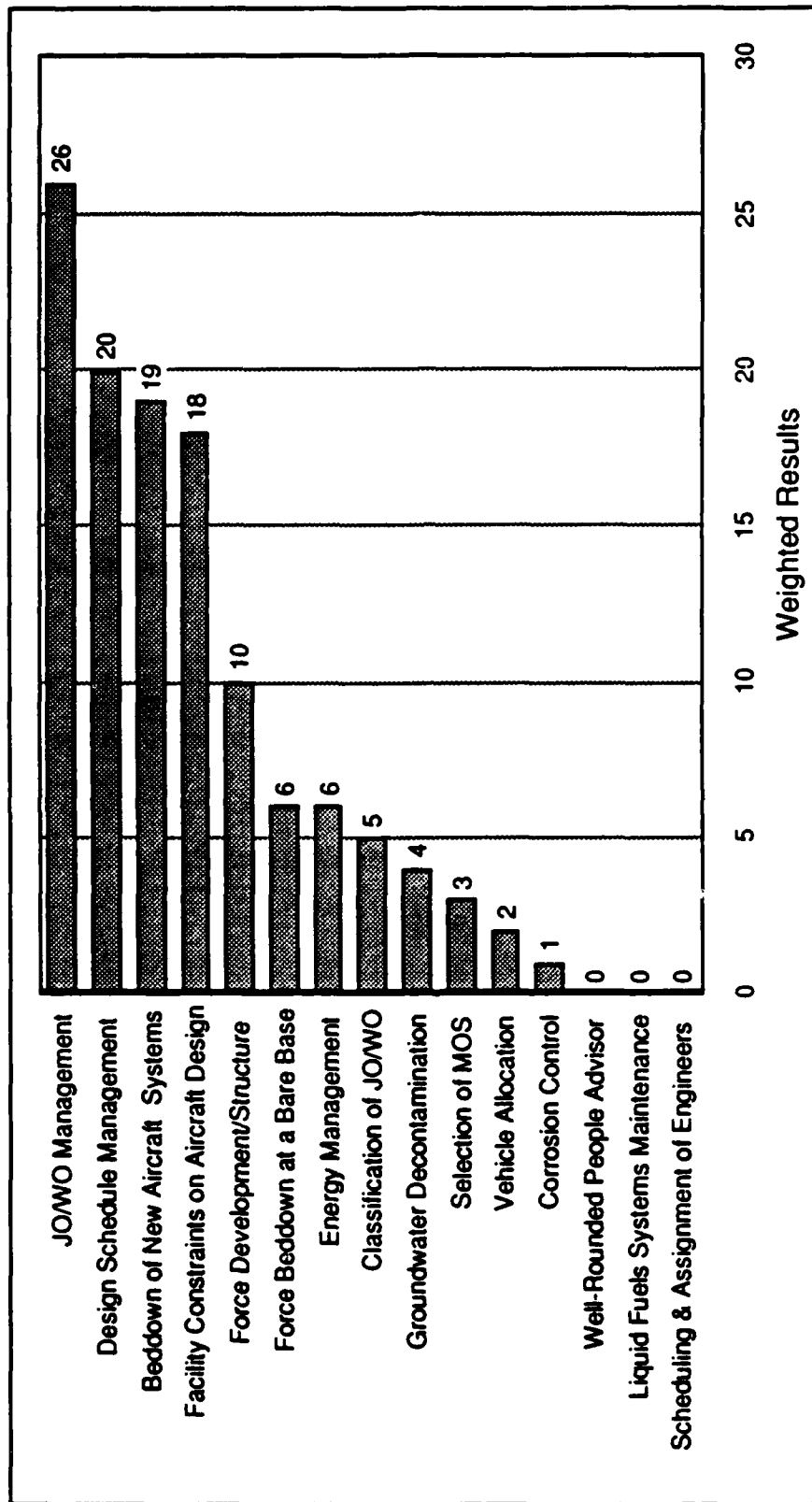


Figure 7
Weighted Selection Results

The top selections from the survey were:

1. Proposal No. 10 - Job Order/Work Order Management.
2. Proposal No. 7 - Design Schedule Management.
3. Proposal No. 14 - Beddown of New Aircraft Systems.
4. Proposal No. 5 - Facility Constraints on New Aircraft Designs.
5. Proposal No. 4 - Force Development/Force Structure.

These five proposals do not exclude the other proposals as potential expert systems or from eventual development. They do reflect the expert systems that would possibly be highest in demand. Also, further definition of the expert systems with the experts and the users needs to be done prior to development.

Selected Proposals

Each of the selected proposals is further defined below.

Job Order/Work Order Management. An expert system that handles job order and work order management would be most effective if developed for the WIMS or the next generation of civil engineering computer systems and be used Air Force wide. The scope of the system, as presented, is quite broad and might make development difficult. The system will need to be constructed in modules, to make each module sufficiently narrow enough to develop (Zody, 1988, Wise, 1988).

The expert system would gather information about production rates, material availabilities, and the job orders and work orders to be accomplished. The system would also schedule the work per the work classification, status of materials, manpower availability, and user

discretion. The expert system would be generic, but elements of the program could be customized for individuals bases. Program elements such as the priorities of different classifications, the percentage of scheduled versus unscheduled work, and preventive maintenance could be changed at the base level (Zody, 1988, Wise, 1988).

Beyond scheduling, the system might flag bottlenecks in the flow of work and materials so managers could work to relieve the problems. As part of the scheduling process, the expert system could automatically develop alternate schedules based on possible different contingencies, for example, weather or exercises (Zody, 1988, Wise, 1988).

Design Schedule Management. This expert system is similar to the job order/work order expert system, because it would probably be beneficial on an Air Force wide level. This expert system probably best implemented on WIMS or the next generation of civil engineering computer systems so the expert system could access data directly (Lollis, 1988, Wise, 1988).

Ideally, the system would provide assistance with managing projects starting in programming and continuing until construction is complete. The system could be modularized to handle projects in the different stages. Impacts of not accomplishing projects could be listed with the projects. As the schedules change, the impacts could be compared so that managers are able to make the most prudent solutions (Lollis, 1988, Wise, 1988).

Expert's strategies for managing project funding and design schedules could be elicited and captured within the expert system. Differing strategies depending on political and funding environments could be available for the user on the system. Elements of the system might be

changed so that it could be customized to suit the user's preference (Lollis, 1988, Wise, 1988).

Beddown of New Aircraft Systems. This proposal differs from the first two in that it would only be useful at the headquarters and the bases responsible for a new system beddown. The knowledge base would provide nearly all the information and inferences needed to run the expert system; hence, the system could be developed on a personal computer, making it easily transportable (Zody, 1988).

The knowledge base would be captured from individuals that have managed a beddown of a new system and documentation from previous beddowns. The knowledge could be divided in various sections such as dimensional interfaces, mechanical and electrical interfaces, munitions, fuels, environmental concerns, etc.. As new and differing problems come up, they could be entered directly into the knowledge base to update it (Zody, 1988).

As facility designers develop plans for the beddown of the new aircraft system, the expert system could highlight previous problems and solutions. One of the interviewees provided the following example. When the F-16s replaced the F-4s in Europe, there was a difference in the angle of the jet exhaust, which was not planned for by the facility designers. USAFE requires that the aircraft engines be run up in the shelter. Ultimately, a new design and change order had to be issued to modify the shelters for the aircraft. An expert system with this knowledge may help prevent design problems in the future (Zody, 1988).

Facility Constraints on New Aircraft Designs. This proposal is very similar to the last with the exception that it is intended for the design

managers of new aircraft systems. The knowledge base would be captured from individuals that have managed a beddown of a new system and documentation from previous beddowns. It differs from the previous system by providing information intended to assist the aircraft designer, and not the facility designer. Similar to the previous system, the different interfaces between the aircraft and the facilities would be detailed (Lollis, 1988).

As the design manager uses the system, the impact of exceeding the current facilities' constraints could be estimated in dollars. For example, if a new fighter exceeded the width of the hardened shelters currently available in Europe, the rough cost to build new shelters would be determined. Though only a rough cost, the design manager could use the estimate to decide whether the advantage of the extra width was a sufficient enough benefit to offset the additional facility cost (Lollis, 1988).

Force Development/Force Structure. Similar to the previous two systems, this system would probably be limited to the headquarters level. The system would could be used in three different modes: for planning, for exercises, and for actual operations (Cannon, 1988, Showers, 1988).

Developing the forces to go to war is now done largely by rule of thumb. Automating it with an expert system model would allow many different scenarios to be played out before the actual critical deployment occurs. Also, the system could include information such as exercise and operational experience of units and leaders to help in the selection of units for small operations (Cannon, 1988, Showers, 1988).

V. Summary, Conclusions, and Recommendations

Overview

This chapter summarizes the research's objective, methodology and findings, emphasizing conclusions about the effort, making recommendations for further use of the methodology, and suggesting further research.

Summary

Research Objective. The objective of this thesis was to search for applications for expert systems within civil engineering. To accomplish the objective, a methodology was developed to discern which knowledge area had potential for expert system development.

Research Methodology. The methodology used to accomplish the research objective was to follow Waterman's methodology, with some modification. The methodology would assure that the problem area selected would be possible, justified, and appropriate. Eight experienced civil engineers were interviewed during two rounds of questioning. The first round solicited and screened ideas, using the developed methodology, from each of the interviewees. During the second round the interviewees were asked to select the ideas they felt would have the greatest potential benefit to Air Force civil engineering in rank order.

Research Analysis. The first round of interviews generated twenty-one ideas. Some of the ideas were similar and were combined into fifteen proposals presented in the second round of interviews. From the second

round of interviews, five proposals emerged having the greatest potential for benefitting civil engineering:

1. Job Order/Work Order Management.
2. Design Schedule Management.
3. Beddown of New Aircraft Systems.
4. Facility Constraints on New Aircraft Designs.
5. Force Development/Force Structure.

Conclusions

This research has lead to several conclusions.

Conclusion 1: Three types of expert systems will emerge for use by Air Force Civil Engineers: Frequent operations, Infrequent but critical activities, and Training. The fifteen proposals from the first round of interviews fall into these application categories, shown in Table 4. The application categories will indicate the development direction of the applications. Frequent operations and training categories will be used Air Force wide, so they should be developed on WIMS or the next generation of civil engineering computer systems. By installing the expert systems on WIMS or the next generation, the users will have easy access to the expert systems. Infrequent but critical operational systems should be developed on a personal computers, if possible. This development path would save the the capacity on the WIMS for daily usage.

Conclusion 2: Experts and users need to be part of the final selection process. The uncertainty evident in several of the responses indicated the

Table 4 - Application Categories

Frequent Operations:

- Job Order/Work Order Management
- Design Schedule Management
- Vehicle Allocation
- Energy Management

Infrequent But Critical Operations:

- Force Beddown at a Bare Base
- Selection of a Minimum Operating Strip (MOS)
- Force Development/Force Structure
- Beddown of New Aircraft Systems
- Facilities Constraints on New Aircraft Designs
- Groundwater Decontamination
- Well-Rounded People Advisor
- Scheduling and Assignment of Engineers

Training

- Classification of Job Orders/Work Orders
- Corrosion Control
- Liquid Fuel System Maintenance

need for more information from the experts and the users before the final commitment of resources to developing an expert system. The experts would clarify most of the uncertainty identified by the engineering managers. Users could define the requirements of the problems that need to be solved by the expert system. As stated in Chapter 2, user involvement is key to making the system acceptable and workable. Prerau's selection criteria should be followed during the final selection process to generate commitment and assure that no political problems pose an impediment to the development of the proposed expert system (Prerau, 1985: 26-30).

Conclusion 3: Attempting to develop the expertise may be as important as developing the system. It was apparent many of the proposed areas for expert system development were also areas which the interviewees wanted better defined. Attempting to develop expert systems in such areas as job order/work order management and design schedule management may be quite difficult, but would help further define those areas. In short, an expert system development may be one way to concentrate the knowledge for use.

Conclusion 4: Air Force Civil Engineering should anticipate the future and plan for expert systems. As much as spreadsheets and databases are a part of our computer ability now, expert systems will be a part of our future. To adequately anticipate using expert systems in the future, Air Force civil engineering needs to plan now for expert systems. Planning includes providing expert system tools and shells for our expert system development on our next generation of computers. CE's computers should also be able to use expert systems developed by other sources such as the Environmental Protection Agency, U.S. Army Construction Engineering

Research Laboratory, and commercial products. A pool of expertise, engineers knowledgeable in expert systems, needs to be nurtured within Civil Engineering, so civil engineers can develop their own systems.

Conclusion 5: The search for possible expert systems is not completed. Many of the ideas and proposals presented in this thesis would make good expert systems; but many other problem areas have not been discussed. Air base operability is growing as a knowledge area, which might in the near future have a great potential and need for expert systems (Cannon, 1988). As new problems arise, so will the potential for new expert systems.

Recommendations on the Selection Criteria

The methodology worked well, though several changes would improve it. Consideration should be given to eliminating unnecessary questions, adding scales to some questions, and defining a manageable size.

Eliminate Unnecessary Questions. In retrospect Questions 9 and 11 were actually answered by other questions, and are probably unnecessary. Question 9, concerning whether experts were better than novices, was answered 'yes' in every incidence. The more discerning question is Question 7, "Do genuine experts exist?", which was answered 'maybe' three times. Also considered unnecessary was Question 11, concerning the practical value of the expert system proposed. The practical value of the system is actually answered by the justification section.

Scales. The unexpected level of uncertainty in many of the answers points to the need to have scales for four of the questions. The scale would

help to define the gray area in between yes and no for both the researcher and the interviewee.

Question 2, concerning the volatility of the knowledge area was answered 'yes' four times and 'maybe' once. ('No' is the acceptable answer in this case.) Interestingly, three of the times it was answered 'yes', the same idea was answered 'no' by another interviewee, showing diversity in opinion. In all three of the incidents, Question 8 concerning the agreement between experts was also answered 'maybe'.

Question 12 also gave several of the interviewees difficulty in answering either 'yes' or 'no'. Identifying the relative percentage of heuristic solutions and percentage algorithmic solutions would give the researcher a better indication whether an expert system is really appropriate or not. Question 16, concerning how well a task is understood would also be better suited by a scaled response. Scaling these questions in the future would measure the level of uncertainty felt by the interviewees.

The scales could be presented to the interviewees in terms of percentage. For example, using Question 2:

Is the task in a volatile knowledge area? What percentage of the knowledge area is stable and mature?

- a. 100% b. 95% c. 90% d. 85% e. 80% or less

Scaling Questions 8, 12, and 16 in a similar manner would also provide the researcher with a better feel for the subject in consideration. Ultimately, the scaled questions in concert with the other questions would indicate potential for expert system development. Of course, proposals with overwhelming justification could be attempted in the interest of furthering

the knowledge area even if the expert system is on the low end of the potential development scale.

Manageable Size. Describing a manageable size was a very nebulous concept. Attempting to ask the interviewees directly often lead to some very nebulous answers. Further research should be attempted to discern some method for asking this question. The best solution would be a heuristic identifying a manageable size.

Further Research

A number of different paths might extend from this work. Initially, the selection methodology might be used to survey civil engineering Air Force wide. The selection methodology might also be a starting point for the final selection and development of some of the proposals suggested. Ultimately, each of the proposals suggested might be a research topic or several research topics in themselves.

Appendix A: Definitions

Artificial Intelligence - A field aimed at pursuing the possibility that a computer can be made to behave in ways that humans recognize as 'intelligent' behavior in each other (Harmon and King, 1985:257).

Case - A particular, specific problem for which an expert system can perform its task. Cases are used by the knowledge engineers in developing, expanding and evaluating the performance of expert systems (McCain, 1987: 117).

Decision Support System (DSS) - An interactive system that helps managers utilize data and models to solve unstructured problems (Holt, 1987).

Domain Expert - A person who through years of training and experience has become extremely proficient at problem solving in a particular domain (Waterman, 1986: 10).

Expert Systems - Any computer system developed by means of an expert-system-building tool mapping an expert or experts knowledge and expertise (Harmon and King, 1985: 259).

Expert-system-building tool - The programming language and support package used to build an expert system (Waterman, 1986: 11).

Heuristic - A rule of thumb or other device or simplification that reduces or limits search in a problem area. Heuristics differ from algorithms in that heuristics do not always insure a correct answer (Harmon and King, 1985: 260).

Inference - The process by which new facts are derived from known facts. A rule (e.g., If the sky is black, then the time is night), combined with a rule of inference (e.g., Modus ponens) and a known fact (e.g., The night is black) results in a new fact (e.g., The time is night) (Harmon and King, 1985: 261).

Knowledge Engineer - An individual specializing in analyzing problems, acquiring knowledge, and constructing expert systems (Harmon and King, 1985: 262).

Management Information System (MIS) - a system that accumulates, stores, processes, and transmits information (Holt, 1987).

Modus ponens - A rule of logic, asserting that if A implies B, and A is true, then B is true (Harmon and King, 1985: 263).

User - A person who uses an expert system, such as domain expert, a knowledge engineer, clerical staff, or anyone that uses the developed system (Waterman, 1986: 10-11).

Appendix B: Prerau's Selection Criteria
for an Appropriate Domain for an Expert System

BASIC REQUIREMENTS

- The domain is characterized by the use of expert knowledge, judgment, and experience. The goal of the project is to extract a portion of an expert's knowledge, judgment and experience, and put it in a program.

- Conventional programming (algorithmic) approaches to the task are not satisfactory. If a conventional approach will work well, there is usually less technical risk to using it rather than an expert system approach. Note, however, that expert system methodology may offer some additional advantages over conventional techniques, such as the expected ease of updating and maintaining a knowledge base and the ability to explain results.

- There are recognized experts that solve the problem today. If an area is too new or too quickly changing, there may be no real experts. However, these are often the areas that are suggested for expert system developments.

- The experts are probably better than amateurs in performing the task. Thus, the task does require expertise.

- Expertise is not or will not be available on a reliable and continuing basis, i.e., there is a need to "capture" the expertise. Thus, there is a need for the expert system. For example: (1) expertise is scarce, (2) expertise is expensive, (3) there is a strong dependence on overworked experts, and/or (4) expertise is available today, but will be unavailable, or less available, in the future.

- The completed system is expected to have a significant payoff for the corporation.

- Among possible application domains, the domain selected is that one that best meets overall project goals regarding project payoff versus risk of failure. For example, a conservative approach would be to attempt to develop a system that would meet some criterion for minimum payoff if successful, and that seems to offer the best chance of success.

TYPE OF PROBLEM

- The task primarily requires symbolic reasoning. For a task that primarily involves numerical computation, consideration should also be given to other programming approaches.
- The task requires the use of heuristics, e.g., rules of thumb, strategies, etc. It may require consideration of an extremely large number of possibilities or it may require decisions to be based upon incomplete or uncertain information. A strength of expert systems is their ability to handle heuristics. Problems with very large numbers of possibilities or with incomplete or uncertain information are difficult to attack by conventional approaches, but may be amenable to expert system methodologies.
- The system development has as its goal either to develop a system for actual use or to make major advances in the state of the art of expert system technology, but does not attempt to achieve both of these goals simultaneously. Doing both simultaneously is laudable, but more difficult.
- The task is defined very clearly: At the project outset, there should be a precise definition of the inputs and outputs of the system to be developed. This is a good attribute of any task. However, it is not necessary that the task definition be fixed for all time. As the system evolves and task situations change, it should be possible to change the task definition accordingly.

THE EXPERT

- There exists an expert to work with the project. This is the source of expertise.
- The expert's knowledge and reputation must be such that if the expert system is able to capture a portion of the expert's expertise, the system's output will have credibility and authority. Otherwise, the system may not be used. (This may not be necessary in a domain where an accepted test for "goodness" of result exists.)
- The expert has built up expertise over a long period of task performance. Thus, the expert has had the amount of experience necessary to be able to develop the insights into the area that result in heuristics.

- The expert will commit a substantial amount of time to the development of the system. This is often a problem. The best experts, in the most important corporate areas, are usually the ones that can be least spared from their usual position.

- The expert is capable of communicating his knowledge, judgment, and experience, and the methods used to apply them to the particular task. It is important to find an expert that has not only the expertise, but also the ability to impart it to the project team, whose members probably know little or nothing about the subject area. The expert should be able to introspect to analyze reasoning process clearly to the project team, and to discuss it with them.

- The expert is cooperative. The expert should be eager to work on the project or, at worst, nonantagonistic.

- The expert should be easy to work with. The project team and the expert will be spending a lot of time together.

- The expertise for the system, at least that pertaining to one particular sub-domain, is to be obtained primarily from one expert. This avoids the problem of dealing with multiple experts whose conclusions or problem-solving techniques do not agree. However, there may be some advantages to using multiple experts--e.g., strength of authority and breadth of expertise in sub-domains.

- If multiple experts contribute in a particular sub-domain, one of them should be the primary expert with final authority. This allows all the expertise to be filtered through a single person's reasoning process. (Note that some techniques have been developed, in disciplines such as economic modeling and technological forecasting, to allow combining inputs from multiple experts.)

PROBLEM BOUNDS

- The task is neither too easy (taking a human expert less than a few minutes) nor too difficult (requiring more than a few hours for an expert). If the task is too easy, the development of the system may not warrant the effort; if too difficult, the amount of knowledge needed may be beyond the state of the art in knowledge base size.

- The amount of knowledge required by the task is large enough to make the knowledge base developed interesting. If it is too small, the task may be more amenable to another approach--e.g., a decision tree.

- The task is sufficiently narrow and self-contained: the aim is not for a system that is expert in an entire domain, but for a system that is an expert in a limited task within the domain. This more tightly bounds the task, which should help keep the size of the knowledge base bounded.

- The number of important concepts (e.g., rules) required is bounded to several hundreds. This is a reasonable size for an expert system, though the number can go into the thousands.

DOMAIN AREA PERSONNEL

- Personnel in the domain area are realistic, understanding the potential of an expert system for their domain, but also realizing that thus far few expert systems have resulted in actual production programs with major industrial payoff. The system recipients should not be overly pessimistic. The project team may have to educate them to understand what are reasonable expectations.

- Domain area personnel understand that even a successful system will likely be limited in scope and, like a human expert, may not produce optimal or correct results 100% of the time. The expert system will probably be no better than a limited version of the expert--this must be enough.

- There is strong managerial support from the domain area, especially regarding the large commitment of time by the experts(s), and their possible travel or temporary relocation, if required. This should all be agreed upon up front.

- The specific task within the domain is jointly agreed upon by the system developers and the domain area personnel. This helps ensure that the system, if successful, will be useful and will be used.

- Managers in the domain area have previously identified the need to solve the problem which the system attacks. This is strong evidence that the system is needed and makes managerial support more likely.

- The project is strongly supported by a senior manager, for protection and follow-up.
- Potential users would welcome the completed system. If not, will the system ever be used? The project team should consider how to make the system unthreatening to the users and welcomed by them.
- The system can be introduced with minimal disturbance of the current practice. This will make the users' acceptance of the system more likely.
- The user group is cooperative and patient.
- The introduction of the system will not be politically sensitive or controversial. If not, the potential resulting problems should be considered in advance. One typical problem: The control or use of the system goes across existing organizational boundaries.
- The knowledge contained by the system will not be politically sensitive or controversial. For example, there may be certain practices, embodied in heuristics, which may prove embarrassing if written down, such as how certain customers are treated relative to other customers.
- The system's results will not be politically sensitive or controversial. If there will be corporate parties who will challenge the system if its results do not favor them politically (e.g., on appropriation of funds), then it will be much harder to gain system acceptance.

OTHER DESIRABLE FEATURES

- The system can be phased into use gracefully: Some percentage of incomplete coverage can be tolerated (at least initially), and the determination of whether a sub-problem is covered by the present system is not difficult. If the system does not have to do everything in order to do something, it can be put in place much sooner. The more difficult problems can be solved later, if at all.
- The task is decomposable, allowing relatively rapid prototyping for a closed small subset of the complete task; and then slow expansion to the complete task. This makes development much easier.

- The task is not all-or-nothing: Some percentage of incorrect or nonoptimal results can be tolerated. The more toleration for incorrect results, the faster the system can be deployed and the easier it will be to win system acceptance. For example, in a domain where even the best experts are often wrong, system users will not be as upset by an incorrect result from the system.

- The skill required by the task is taught to novices. Thus, the task is not "unteachable," and there is some experience with teaching the domain knowledge to neophytes, such as the project team (and ultimately, the system). Furthermore, this usually means that there is an organization to the knowledge that can prove useful (at least initially) in building the system.

- There are books or other written materials discussing the domain. If this is true, then an expert has already extracted and organized some of the domain expertise. As in the previous point, this organized knowledge might prove useful (at least initially) in building the system. Note, however, that one benefit of capturing an expert's domain knowledge might be to make a step toward formalizing a domain that has not been treated in a formal manner before.

- The task's payoff is measurable. If not, it is harder to demonstrate success to skeptics.

- Experts would agree on whether the system's results are good (correct). If not the system's results are open to challenge, even if the system accurately embodies the expert's knowledge.

- Test cases are available. This make development much easier.

- The need for the task is projected to continue for several years. The need must exist enough beyond the period of system development to generate the payoff.

- The domain is fairly stable. Expected changes are such that they utilize the strengths of expert systems (e.g., ease of updating or revising specific rules in a knowledge base, but will not require major changes in reasoning processes). An unstable domain may yield a situation where a large number of previously developed knowledge structures (e.g., rules) are no longer valid but cannot easily be change without redoing the entire development process.

- The effects of corporate developments that will significantly change the definition of the task can be foreseen and taken into account.

- No alternative solution to the problem is being pursued or is expected to be pursued. However, if a project goal is to compare expert system technology to other technologies this may be just what is desired.

- The project is not on the critical path for any other development, and has no absolute milestones for completion. The use of expert system technology for real corporate applications is still relatively new, and so any development has some risk. Thus, the less dependent other activities are, the better.

- At the outset of the project, the expert is able to specify many of the important concepts. This gives good promise of project success.

- The task is similar to that of a successful existing expert system. This also makes success more likely.

- Any requirement for real-time response will not involve extensive effort. Though it is certainly possible to develop a system for a problem with a real-time requirement, the considerations involved divert effort from the primary task knowledge acquisition.

- The user interface will not require extensive effort. As with a real-time requirement, if the work required is excessive, it could divert effort from knowledge acquisition.

Source: David S. Prerau, "Selection of an Appropriate Domain for an Expert System," The AI Magazine, Summer, 1985, pg. 27-30.

Appendix C: Preliminary Selection Criteria

This preliminary selection criteria provides guidance and information concerning the development of expert systems. It is to be used by senior management in reviewing problem areas that might be helped by an expert system. After successfully screening a possible application, the expert or experts and the users should become involved with the final selection, using Prerau's selection criteria (Prerau, 1985: 26-30).

Typically, all the answers to this preliminary selection criteria must be yes (except of the Justified section and questions 2 & 15), to recommend proceeding with the development of an expert system. The justified section requires only one yes response.

Realistic

1. *Will the expert system tackle problems managers have tackled before?* If the problem currently cannot be solved, an expert system will not help (Cross, 1988).
2. *Is the task in a volatile knowledge area?* Because of the development time, expert systems are generally developed only in mature knowledge areas (Cross, 1988).

Justified

3. *Does the task have a high payoff?* The extensive development costs must have a substantial offset or payoff to be a justified venture for an organization (Waterman, 1986: 130).
4. *Is the human expertise scarce or being lost?* The expert system can be justified scarce expertise or expertise being lost (Waterman, 1986: 130).
5. *Is the expertise needed in many locations at once?* Expert systems can easily be reproduced to be used at many locations at once (Waterman, 1986: 130).
6. *Is the expertise needed in a hostile environment?* Expert systems can be risked in environments of high risk, without risking the experts (Waterman, 1986: 130).

Expertise

Expert Characteristics

"... experts are not only proficient, but smooth and efficient in the actions they take" (Johnson, 1983: 78).

"Real experts not only produce good solutions, but often find them quickly, while novices tend to take much longer to find the same solutions" (Waterman, 1986: 25).

7. *Do genuine experts exist?* If genuine experts do not exist, development of the system may be very difficult or impossible (Waterman, 1986: 129).
8. *Do the experts agree on solutions?* If the experts do not agree on the solutions, then the expert system may be of little or no use (Waterman, 1986: 130).
9. *Are experts better than novices at performing the task?* If a novice can perform as well as an expert, then there is probably no advantage in developing an expert system (Prerau, 1985: 27).
10. *Can the experts can articulate their methods?* Ultimately, the experts' methods must be represented by the knowledge base within the expert system. If the experts cannot articulate their methods, the knowledge base cannot be constructed (Waterman, 1986: 129).

Task

11. *Does the task have a practical value?* The task should cover enough information that users would be interested in using an expert system for assistance (Waterman, 1986: 132).
12. *Does the task use heuristic solutions versus algorithms?* Heuristic solutions are based on strategies and rules of thumb, based on incomplete or uncertain information. Algorithmic solutions use exhaustive methods based on theoretical, mathematical, and/or empirical techniques. Expert systems work best with heuristic information (Waterman, 1986: 130).
13. *Can the task be manipulated symbolically?* This deals with the type of problem. Another way to consider the same question is the telephone test. Could an expert, given the necessary time, guide a novice through the problem? If so, the task could probably manipulated symbolically (Waterman, 1986: 130).

14. *Do the problems encountered share some of the same common characteristics?* Problem that the expert system will solve should have some common characteristics or data inputs to the system. If they do not, the development of an expert system will be very difficult (Cross, 1988).
15. *Are conventional programming techniques satisfactory?* Expert systems are often thought of as a last resort because of the extensive time and cost invested into the development effort. If no other programming technique will do all that is required or come close, then an expert system may be the answer (Prerau, 1985: 27).
16. *Is the task is well understood?* This question complements Question 10. "If the task is so new or so poorly understood that it requires basic research to find solutions, knowledge engineering will not work (Waterman, 1986: 129).
17. *Can the skill required can be taught to novices?* If the skill cannot be taught to novices, it is unlikely that it can be developed into an expert system (Prerau, 1985: 29).
18. *Is the task is of a manageable size?* The task should be sufficiently narrow and self-contained. Another way to think about it is, the expert system should be the expert for a limited task within the knowledge domain (Waterman, 1986: 132).
19. *Are cases are available to develop and verify the validity of the system?* The development and the verification of the expert system depend on the having cases illustrating the problem encountered to the knowledge engineer (Prerau, 1985: 29).

Other Considerations

20. *Is the task difficult enough to require an expert?* The problem should not be too easy, otherwise the knowledge could be transferred directly to the user (Waterman, 1986: 132).
21. *Does the task require commonsense?* Expert systems do not deal well with commonsense reasoning problems (Waterman, 1986: 129).
22. *If commonsense is required, can the user provide it?* If the user can provide the commonsense required for the problem, then the expert system would be of use (Waterman, 1986: 129).
23. *Does the task require cognitive skills only?* If senses, such a refined sense of smell, are required, then the user will have to supply these skills (Waterman, 1986: 129).

Appendix D: List of Interviewees

- Col George E. Cannon Jr., Dean, School of Civil Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH**
- Col Joe L. Hicks, Director of Operations and Maintenance, Engineering and Services, Headquarters Air Force Logistics Command, Wright-Patterson AFB OH**
- Col Thomas E. Lollis, Deputy Chief of Staff for Acquisition Civil Engineering, Aeronautical Systems Division, Wright-Patterson AFB OH**
- Col Nicholas A. Scambilis, Base Civil Engineer, Wright-Patterson AFB OH**
- Col James G. Zody, Assistant Deputy Chief of Staff, Engineering and Services, Headquarters Air Force Logistics Command., Wright-Patterson AFB OH**
- Maj Mark N. Goltz, Department Head, Department of Management Applications, School of Civil Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH**
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- Maj Timothy G. Wise, Executive Officer to the Deputy Chief of Staff, Engineering and Services, Headquarters Air Force Logistics Command, Wright-Patterson AFB OH**

Appendix E: First Round Interview Data

Prop Idea		Acceptable Answer	QUESTIONS																						
			I					II					III					IV					V		
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	2	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
1	Proposed Expert System																								
1	1	Classification of Repair	Y	N	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
2	2	Force Beddown at a Bare Base	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
15	15	Prime BEEF - Priorities, checklist, CPM	Y	Y	Y	Y	Y	M	Y	Y	Y	Y	Y	Y	Y	Y	M	M	Y	M	Y	Y	Y	M	
18	18	Bare Base Layout	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
3	3	Selection of Minimum Operating Strip (MOS)	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
4	4	Force Development/Force Structure	Y	Y	Y	Y	Y	N	N	M	Y	Y	Y	Y	Y	Y	N	M	Y	M	Y	Y	Y	Y	
20	20	Tasking Mobility Forces/Force Structure	Y	N	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
5	5	Facility Constraints on New Aircraft Designs	Y	N	Y	Y	Y	N	N	Y	M	Y	Y	Y	Y	Y	M	Y	N	Y	M	Y	Y	Y	
6	6	Corrosion Control	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	M	
13	13	Paint Selector	Y	Y	Y	N	Y	N	Y	Y	M	Y	Y	Y	Y	Y	Y	Y	N	Y	M	Y	Y	Y	
7	7	Tracking of Design Projects	Y	N	Y	M	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
10	10	Design Schedule Management	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	M	Y	Y	Y	Y	
8	8	Allocating Vehicles	Y	N	Y	Y	Y	Y	Y	M	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	M	Y	
9	9	Energy Management	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
10	10	Work Order Management	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	M	Y	Y	Y	Y	M	
19	19	Job Order/Work Order Scheduling	Y	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	
11	14	Well-Rounded People Advisor	Y	N	Y	N	Y	N	Y	Y	M	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	
12	16	Liquid Fuels Systems Maintenance	Y	N	Y	M	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	M	Y	N	Y	Y	Y	Y	Y	
13	17	Beddown of New Aircraft Systems	Y	N	Y	Y	Y	N	N	M	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	M	Y	Y	Y	
14	21	Groundwater Decontamination	Y	M	Y	Y	Y	Y	Y	Y	M	Y	Y	Y	Y	Y	Y	Y	Y	N	M	Y	Y	Y	
15	22	Scheduling & Assignment of Engineers	Y	N	Y	Y	Y	N	Y	Y	M	Y	Y	Y	Y	Y	Y	Y	M	Y	Y	Y	M	Y	Y

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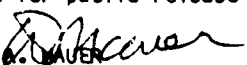
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ABSTRACT

Expert systems have great promise for increasing productivity and effectiveness. As budget cuts continue into the future, Air Force Civil Engineering will be increasingly concerned with its productivity and effectiveness. This thesis searched for Air Force Civil Engineering expert system applications using a preliminary selection criteria to discern the knowledge areas having expert system potential. Interviews were conducted with experienced civil engineers to gather the ideas.

The primary objective of this thesis was to develop a preliminary selection criteria. Donald Waterman's selection criteria was used as the basis. The questions within the selection criteria were reordered with the most discriminating questions first, to eliminate unfruitful ideas quickly. Other discriminating questions were added to the selection criteria as necessary for clarification and amplification.

Eight experienced civil engineers were interviewed during two rounds of questioning. The first round of interviews solicited and screened ideas, using the preliminary selection criteria. The first round generated twenty-one ideas, which were combined into fifteen proposals. In the second round, interviewees selected proposals having the greatest potential benefit to Air Force Civil Engineering in order. Five proposals emerged from the second round of interviewing: Job Order/Work Order Management, Design Schedule Management, Beddown of New Aircraft Systems, Facility Constraints on New Aircraft Designs, and Force Development/Force Structure.

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